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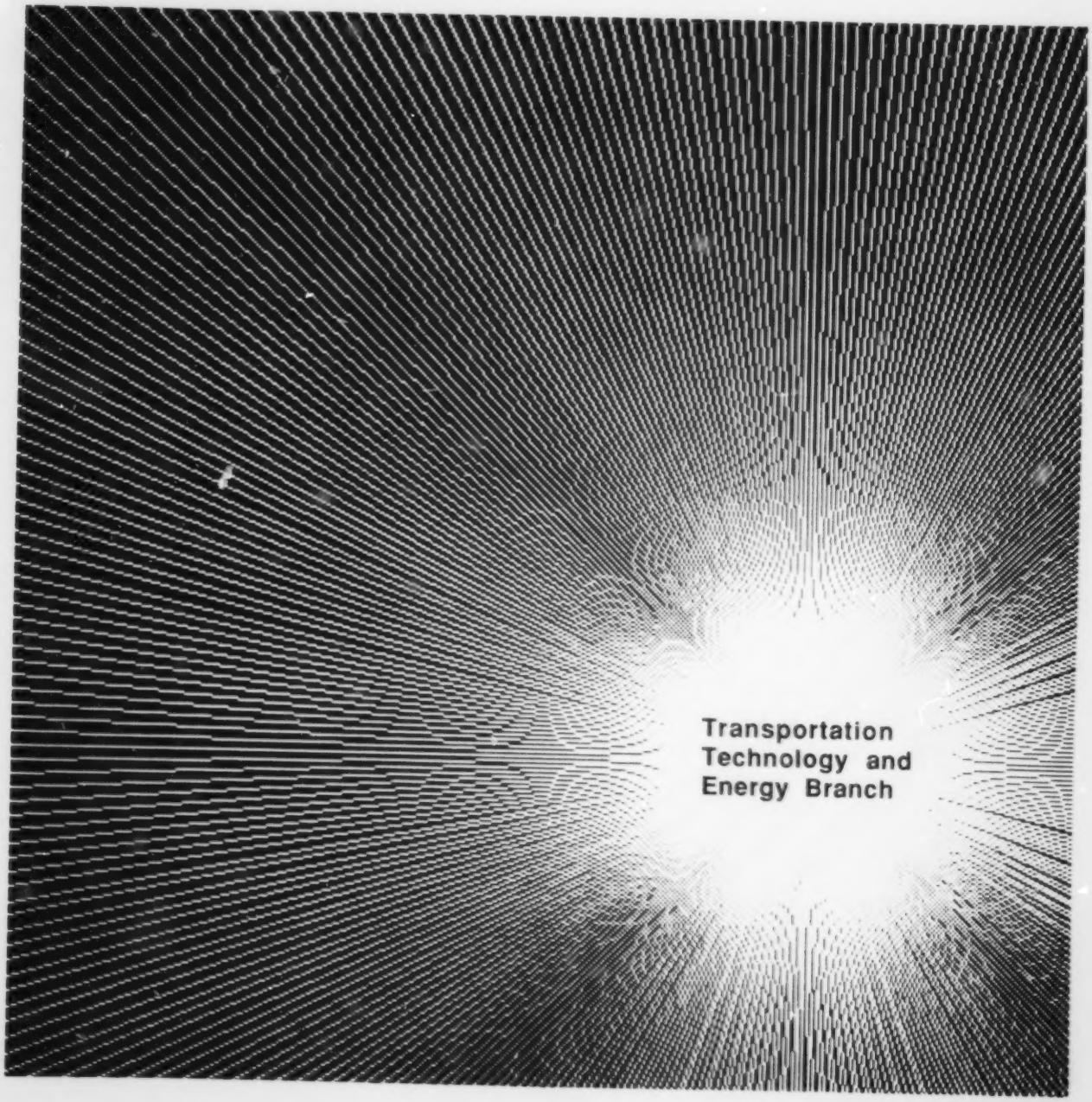

Commuter Rail Services Electrification Study

RT-92-01

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Technical Report Documentation Page

Commuter Rail Services Electrification Study

Prepared by:	**CPCS Ltd.**
Prepared for:	J. Young, Project Research Engineer Rail and Advanced Transportation Systems Office Transportation Technology and Energy Branch Ministry of Transportation and L. Keachie, Project Engineer Engineering GO Transit
Report No.:	RT-92-01
Date:	June 1992
Published by:	Transportation Technology and Energy Branch Ministry of Transportation
Abstract:	Previous studies regarding electrification of GO Transit commuter rail operations in the Greater Toronto Area were reviewed updated and the information consolidated. Anticipated service expansions and improved service levels were included in the analysis. Capital costs were evaluated, along with operating costs of a variety of possible electrified railway scenarios. Electrification system design, rolling stock, signalling systems and clearance requirements were also described. Environmental impacts, emissions (relative to diesel locomotives) and energy utilization were also examined.
Key words:	commuter rail, electrification, railway electrification costs, power supply, electric locomotives
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RT-92-01

Commuter Rail Services Electrification Study

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7 May 1992

Enclosed is a copy of the recently completed GO Transit Commuter Rail Services Electrification Study. The report was a joint effort by the Ministry of Transportation of Ontario and GO Transit.

The primary objective of this report was to identify the technical requirements and considerations for electrifying the GO Transit Rail System.

This study is one of a number of studies to be completed on the concept of electrification of the GO Transit system. Further studies will need to be completed prior to any commitments by the Province of Ontario and GO Transit.

All the information contained within this report is of a conceptual nature and should be viewed only in this context.

Sincerely,

Richard C. Ducharme
Executive Director
Engineering, Development & Plant

Encl.

Final Report
Presented to
GO Transit and
Ministry of
Transportation

COMMUTER RAIL SERVICES ELECTRIFICATION STUDY

Toronto, Canada

March 1992

Prepared by
CPCS Ltd.
in association with
Hatch Associates Ltd.

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Final Report Presented to GO Transit and Ministry of Transportation

COMMUTER RAIL SERVICES ELECTRIFICATION STUDY

Prepared by
CPCS Ltd.

EXECUTIVE SUMMARY

The objectives of this study were to review, update and consolidate previous electrification studies which have been carried out for GO Transit, to include anticipated service expansions and improved service levels and to assess the environmental impact of electrification on the Greater Metropolitan Toronto Area.

Although electric railways have been in existence for over one hundred years, significant technological advances have been made in recent decades and will continue to be made in the future. These technological advances have resulted in reduced fixed equipment costs, reduced maintenance costs and increased energy efficiency. The accelerating development of technologies make it appropriate to review the economics of electrification on a regular basis.

In order to make a basic assessment of the electrification options a train service level has been assumed for the purposes of this study. This train service provides for 10 minute peak/30 minute offpeak frequency for the Lakeshore Line and 20 minute peak/60 minute offpeak frequency on the Branchlines. Existing service routes have been extended to Hamilton, Oshawa and Guelph. Other termini remain as at present - Milton, Barrie, Richmond Hill and Stouffville. Section 2 outlines the assumptions and criteria adopted as the basis for further analysis.

Section 3 briefly presents a review of five previously concluded GO Transit electrification studies. This section yields a historical perspective on both electrification technologies and philosophies.

Many of the capacity increases and service enhancements which GO Transit anticipates in the medium and long terms have been incorporated within the analysis of this study. These are summarized in Section 4.

Sections 5 and 6 present the train operation patterns on each of the lines operated by GO Transit, itemize the more significant benefits and drawbacks of diesel locomotive, electric locomotive and electric multiple unit (EMU) operation and assess rolling stock and rolling stock maintenance with specific reference to current North

American and European developments. Conversion of GO Transit bi-level coaches to EMU traction power cars is not recommended. A comparison of acceleration curves for the rolling stock options is presented along with up-to-date capital cost estimates and discussions relating to comparative maintenance needs.

Section 7 provides a review of the environmental considerations associated with the electrification of the GO Transit Rail system. Potential positive and negative impacts have been outlined and discussed for both the natural and social environments. Significant positive impacts of electrification include air quality, service and economic considerations while the visual impact of electrification is potentially negative in perception. The visual impact can be minimized through the structural design of the catenary and support masts and optimization of the distance between the supports.

The train performance calculations (TPC's) for the various scenarios to be analyzed are outlined and discussed in Section 8. The objectives were to: determine the energy requirements for each scenario, examine the journey times under each scenario and to provide basic power profiles in order to select the appropriate overhead contact system (OCS) for electrification. Journey times could be reduced by 20% but the higher acceleration and speeds increase energy consumption. The reduction in journey times does, however, yield a proportional decrease in the total fleet size required to provide the same service. Unless there is an unexpectedly high increase in passenger volume in the next 10 years, no technical limit is foreseen for diesel operation. Other energy related issues such as regeneration, peak shaving and cogeneration are also examined.

Section 9 addresses the electrification of GO Transit from a technical viewpoint. The section concludes that given GO Transit's needs, considerations of future expansions and joint trackage use with other mainline train operations the +/- 25kV autotransformer system to be the most appropriate technology. Optimum designs of OCS are discussed in relation to both operation and installation. Optimum locations and sizes of transformer feeder stations (railway substations) are determined with security of railway operations as the fundamental criteria. Cost estimates are developed for OCS on a per single kilometre basis and for the feeder substations and related equipment.

Section 10 addresses the clearances needed for electrification on the lines where GO Transit now operates or may operate in the future. The possible need to increase vertical clearances could introduce significant additional costs to an electrification project affecting its overall viability. The study has identified 17 road/rail overpasses and 2 pedestrian overpasses which will require vertical clearance improvement to accommodate electrification. The road/rail overpasses may be improved using localized track lowering or undercutting. The pedestrian overpasses may be rebuilt or replaced. Additional headroom would be required at signal structures and could be effected by relocating the existing units on higher concrete piers. The Union Station roof represents the major obstacle in obtaining standard clearances throughout the GO Transit network. The study assumes that the entire train shed structure from the platforms upwards will be replaced. The section concludes with a summary of costs required to achieve standard electrification clearances.

The implementation of electrification and the impact of electrification upon both signalling and communications are examined in Sections 11 and 12. For the OCS, the study reviews the installation of OCS, outlines OCS maintenance needs and presents typical implementation rates. Current signalling costs have been used to estimate the upgrading of railway facilities since most existing signalling equipment on rails and at trackside is incompatible with electrification.

Section 13 outlines the four scenarios to be evaluated and summarizes all the various cost elements previously developed on a scenario-by-scenario basis. These cost elements are categorized as capital costs, rolling stock requirements, operating costs, energy needs, maintenance costs and estimated seat kilometres. These costs and quantities are carried forward into Section 14 - Economic Analysis. This section also outlines current market conditions that affect capital and energy items and also outlines other regional benefits to GO Transit electrification which are outside the scope of this study.

The unit cost estimates used to evaluate the costs of diesel operation and electrification of the GO Transit system over the study's 30 year planning horizon are presented in Section 14. The analysis is done on a scenario basis yielding a life cycle average cost per seat-kilometre. Sensitivity analyses were conducted on each

addressed were the cost of diesel fuel, the traffic level, signalling cost, OCS cost and the price of electric locomotives. As would be expected due to the high capital cost of electrification infrastructure, scenarios 3 and 4, the two full electrification scenarios, have a significantly higher economic cost than scenario 1 - full dieselization and scenario 2 - dieselization of the branch lines and electrification of the Lakeshore line only. The differences between the present values of scenarios 2, 3 and 4 from scenario 1 are: +9.7%, +28.8% and +32.3%.

Section 15 presents a list of references and a bibliography which were compiled during the execution of this study.

In summary, scenario 2, electrification of the Lakeshore line achieves most of the environmental benefits and improvements to service quality at a modest increase in economic cost within the range of accuracy of the estimates. However, for practical purposes, the increase in economic cost of scenarios 2, 3 and 4 over that of scenario 1 - continued full diesel operation (respectively $101.7 million, $301.1 million and $337.6 million) could be viewed as the cost of the environmental benefits and service improvements and evaluated in that context.

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1.

INTRODUCTION

1. INTRODUCTION

1.1 THE OBJECTIVES OF THIS STUDY

Railway electrification is being examined on an ever increasing basis as an alternative to continuing to operate and expand diesel-electric railway services. This examination focuses, in many instances, on issues unrelated to cost and financial justification. These issues include environmental concerns, service levels and frequency, ridership and the marketing of mass transit services to name but a few.

GO Transit as a supplier of rapidly expanding rail commuter services in the Metropolitan Toronto Area must continually update its own position within many of these issues not only to possess all the necessary information with which to decide its long-term policy on energy consumption but also to be able to explain its position adequately at any step of the decision making process.

Issues which were of low priority a decade ago are prominent today and technology which was in development at that time is now industry standard. GO Transit within the last decade (latest 1983) has commissioned several studies to assess the feasibility of electrifying its routes. This topic must be revisited on a regular basis to update both the technical and non-technical factors affecting its feasibility.

The Consultant's objectives in carrying out this study on behalf of GO Transit were to review, update and consolidate previous studies as well as to append new topics, considerations and constraints that need to be brought to the attention of GO Transit. The Consultant has reviewed potential operational and environmental benefits, defined the critical service factors that would contribute to electrification, discussed potential service options that would stem from a decision to electrify and identified the core technical criteria that will form the basis for future policy and planning analyses on the part of GO Transit.

This report acknowledges the very competent and detailed work presented in earlier studies and in addition, highlights some significant ongoing technological developments (particularly in rolling stock) and examines some of the broader

impacts of electrification such as maintenance, safety, signalling and property development. The report also notes other studies, for example the proposed High Speed Train Corridor, as their mandates may affect the feasibility of GO Transit Electrification.

1.2 DEVELOPMENT OF ELECTRIC RAILWAY TECHNOLOGY

In presenting railway electrification during the last two decades, the Consultant has noted the substantial interest shown in this subject by railway staff and members of the public. Many have appreciated a brief review of electric railway development, the reasons for differences between the operational capabilities of electric and diesel-electric locomotives and the characteristics of high voltage electricity supply to railways.

Within this context, the Consultant presents brief reviews of the above subjects for non-specialist readers of this report.

1.2.1 Background

Practical electrified railways have been established for over one hundred years for the purposes of passenger and freight transportation. This raises the popular question of whether electrified railways are obsolete or whether modern electrified railway studies and proposals are re-inventing the wheel at great expense.

The credibility of modern studies and electrification work is enhanced by considering the continuous evolution of electric railway technology, of which some salient points will be outlined below.

Advantages of electric traction over steam were clear at the beginning of the twentieth century; particularly the avoidance of air pollution, fuel economy, high tractive power in single units and much reduced maintenance times. Very successful applications were established in the urban corridors of the Northeast U.S.A., including lines into and under major cities such as New York. The principal disadvantage, particularly in North America, was the cost of carrying electric power conductors out over vast

distances of sparsely developed country. In that environment a curious yet remarkably successful hybrid locomotive evolved wherein a diesel generator, a mobile power station, was placed into the electric locomotive. This successful hybrid virtually eliminated or concealed electric locomotive development in many countries for several decades. Concurrently the automobile and diesel bus eliminated many street passenger railways and curtailed any expansion of city suburban electrification networks.

Recurring doubts about economic availability of fuels for vehicle engines, automobiles and locomotives, coupled with the accumulation of noise, fumes and oily residues in dense urban communities have once again made electric railway development attractive in urban areas and, by extrapolation of operating economics, into inter-urban links up to several hundred kilometres.

Technology development for electrification divides logically into three parts.

- Generation of electricity and distribution along railway routes;
- Transfer of electricity to the moving locomotive;
- Creation and control of traction power in the locomotive.

For passenger railways the "locomotive" may in reality be several locomotives existing within and/or below several passenger cars, i.e. the Electric Multiple Unit train. But in discussing the evolution of technology, the distinction of EMU versus locomotive is not significant. Practical problems and technological evolution will be summarized by reversing the order of the above three parts. All are inherently interrelated.

1.2.2 Locomotives

Control of a locomotive is fundamentally control of pulling ability (tractive effort) and speed. Many types of electric motor have been used in electric locomotives but effective control is fundamentally the ability to control voltage (volts) and current (amps) and, in some cases, frequency (hertz) of ac, alternating current. Direct Current (dc), has no frequency. Several types of low power electric motor evolved quite early on to operate at up to a few hundred volts and a few hundred amps either

dc and/or low frequency ac (up to 25 hertz). Many mechanical drive connections between motors and wheels have been used but the most popular is one motor driving one axle through one set of reduction gears. This arrangement in broad terms defines typical size, weight and speed of a traction motor. Electrically such motors are now working at up to 1500 volts and up to 1500 amps (order of magnitude figures). On a standard gauge railway, the evolution of improved electrical insulation has resulted in horsepower capability rising to about 1200 horsepower per motor axle.

Historically, the effective control of dc was expensive (large rotary convertors on the locomotive) and/or inefficient (energy wasted in resistances). Supply voltage was a multiple of motor voltage - typically 750 or 1500 for 750 volt motors, 1500 or 3000 for 1500 volt motors. Modern solid state controllers can theoretically chop down even higher dc supply voltages efficiently but no economic application has appeared for very high dc voltages.

A century ago, it was recognized that a transformer was an efficient way to regulate voltage if fitted with many low voltage connections (taps). An ac traction motor could be efficiently controlled by switching on as much low voltage as required. Electricity could be fed to the transformer as alternating current at several thousands volts. Twelve to fifteen kilovolts (kV) became practical standards. (From the mid 1950's and 1960's these standards were raised, for new systems, to 25 kV and 50 kV.) However, effective and efficient control of an ac locomotive still required that either low frequency ac or dc traction motors were used. Thus the locomotive required a large rotary converter machine or required an electricity supply at low frequency. Only since the mid 20th century has it been technically practical to change ac to dc on the locomotive by static (i.e. low to zero maintenance) devices. Firstly mercury arc rectifier tubes, later true solid state rectifiers evolving to thyristors and then evolving, within the last decade, to Gate Turn Off (GTO) devices. Each of the above solid state devices has evolved in size such that only one or two elements can now handle the total current and voltage needs of a traction motor. The GTO has made synthesis of variable frequency motor current technically simple and in so doing enables the brushless induction traction motor to be used efficiently giving reduced maintenance and improved electric braking.

Nearly all electric locomotives (and diesel electric) have theoretical electric braking capability, i.e. the train can be slowed and/or speed controlled descending grades, but not stopped, by using traction motors as generators. Drawing dynamic energy out of the train, and dissipating generated electrical energy in air cooled resistors, or in certain circumstances returning useful electric energy to the railway supply system.

In practice a motor voltage and current control system, distinct from the traction control, must be provided. Regeneration into the railway supply increases control problems both on the locomotive and at electricity supply stations. Regeneration is quite rare but loco resistor braking (Dynamic Braking) is widely adopted both for mountain area freight locomotives and suburban passenger trains.

The above-mentioned GTO's and variable frequency induction traction motors offer a new economic case for both regeneration and braking down to very low speed. The latter represents both further saving of mechanical braking wear and increases energy recovery possible during braking.

To complete this brief review it should be noted that in recent decades, France has continued to develop some distinct and unusual designs based on one electric motor driving two axles (the monomotor bogie) and the use of synchronous motors driven by variable frequency control for traction and braking. However, with GTO development, French work has also converged toward single axle induction motors.

All of these locomotive developments have meant that supply voltage and supply frequency are no longer primary factors in locomotive design. There is an increasing trend toward international standardization of systems with the advantages of interchangeable mass production; for subways and metros 750 volt dc and/or 25 kV ac at public utility frequency (i.e. 50 or 60 hertz); for interurban and freight 25 kV ac; and for remote haul and/or heavy haul 50 kV ac.

New equipment for other system voltages tends to be for new extensions of existing substantial systems, although for reasons noted above, those systems now have little fundamental effect on new locomotive control and motor characteristics. A number of

dual or multi system electric locomotives have been built in recent years where the increased cost was justified for operational convenience.

1.2.3 Power Collection Systems

Locomotive and EMU power (horsepower) is roughly proportional to the product of voltage and amps.

A high power low voltage system (e.g. 750 volts) requires a current draw of several thousand amps per train. This can be handled by having a solid rail-like conductor (3rd rail) near the running rails and several train-mounted collector shoes sliding along that rail. Such high currents are not economically collected above the train due to weight of the overhead conductor(s) and supporting structures needed. 1500 volt and 3000 volt overhead collection systems were developed before advances in ac locomotives in the mid 20th century. Raising supply voltages to 15 kV, 25 kV, 50 kV yield directly proportional increases in available train horsepower for given supply conductors. Track-side safety considerations dictate that high voltage systems should be elevated above the trains.

Overhead conductor systems based on one or more heavy near-horizontal contact wires suspended from spans of sagged (catenary) messenger wire are as old as electric railways. Various configurations of insulators, cantilevers and cable spans can be used to locate messenger and contact wire over the track. The whole system is commonly known as "the catenary" or "OCS" (overhead contact system).

Each locomotive or power unit carries one or more overhead current collection devices, metallic-carbon strips nearly as wide as the locomotive but bowed down at each end. Traditionally the collector strip is elevated so as to rub along the underside of any overhead conductor wire by two parallelogram type, mechanical linkage frames raised by springs and insulated from the locomotive roof. The popular name for this device is pantograph.

Prompted by plans for high speed trains, considerable mathematical and experimental work was applied to pantographs and OCS systems in the mid 20th

century. This has now resulted in lighter and more simple pantograph designs of benefit to all electric trains and has produced relatively simple methods of catenary assembly which can nonetheless be negotiated by modern pantographs at high speed without bouncing and electrical sparking. In addition contact wire wear is almost negligible.

From the locomotive pantograph, the high voltage current passes to a circuit breaker (main safety switch). The concurrent development of compact high voltage (25 kV, 50 kV) circuit breakers has greatly assisted the reliable operation of high voltage locomotives and EMUs.

Many early OCS installations used robust support poles of sufficient height to carry high voltage electricity distribution lines. In the Northeast U.S.A. some such distribution lines were upgraded to 132 kV.

However today, with established public utility distribution systems and corridors and maintenance practices, any joint use of railway OCS poles is very unlikely and undesirable.

1.2.4 Power Supply

The need for early ac locomotives to use low frequency, as noted above, resulted in either railway owned power stations or rotary convertor machines at railway substations. Rotary convertors were also used to produce dc current.

Existing low frequency ac systems are now achieving some benefit from modern solid state frequency changers but such equipment is not needed for new public utility frequency locomotive applications.

dc railway supplies have benefitted from the replacement of rotary convertors, first by mercury arc rectifiers and more recently by solid state rectifiers.

Under practical analysis the percentage voltage drop per kilometre of loaded low voltage (750 volts) railway is very much greater than the percentage drop on a high

voltage system which necessitates frequent transformer rectifier supply points into the 750 volt conductor rail.

High voltage (25 kV, 50 kV) railway power supply operation has been greatly eased by the development in recent years of low maintenance high durability circuit breakers, particularly of vacuum and SF_6 (sulfur hexafluoride) types.

The equipment required at an AC railway supply substation is similar to that at Public Utility substations working in the same range of voltages. General design standards, layout, and much of the equipment are identical.

Control and protective relaying is also similar but adjusted to define the exact characteristics of the railway OCS and moving locomotives. For this reason the detection of faults on the railway OCS is sensitive and affords a high degree of safety.

2.

ASSUMPTIONS AND CRITERIA

2. ASSUMPTIONS AND CRITERIA

At the time of project inception, the Consultant and GO Transit agreed that it was necessary to compile a comprehensive list of assumptions and criteria in order to set the framework within which the scope of the study would be addressed. These assumptions and criteria were selected for their applicability and for their ability not to unduly limit the results of the study.

2.1 POWER DEMAND AND ENERGY ANALYSIS

Detailed Train Performance Calculations (TPCs) for power demand and energy consumption will be performed for the Lakeshore East and West line and for the Richmond Hill line only. Capital and operating costs estimates for the entire GO Transit network will be extrapolated from the results obtained on these lines.

2.2 PLANNED EXTENSIONS TO THE GO TRANSIT NETWORK

For the purposes of this study, it will be assumed that the Lakeshore line will operate between Oshawa and Hamilton, the Georgetown line will be extended to Guelph and the Milton, Barrie, Richmond Hill and Stouffville lines will terminate at their present terminals.

2.3 FORECAST LEVELS OF GO TRANSIT SERVICE

In order to run the TPCs on the Lakeshore and Richmond Hill lines it was necessary to make preliminary assumptions regarding the levels of service that would be reasonable even though the time horizon for the study makes it virtually impossible to forecast with any accuracy.

The train frequency and consist assumptions for these lines will be as follows:

- Base case option with diesel trains, no electrification

  A consist of 10 bi-level cars hauled by one 3000 HP diesel locomotive. The headway during the peak periods 0630-0900 and 1630-1900 will be 10 minutes. The headway during the remaining off-peak periods will be 30 minutes. There will be no scheduled train service between the hours of 0200 and 0500.

- Electric Trains

  The consists and frequencies for the electric locomotive option will be the same as outlined above. The electric locomotive parameters will be found in Section 8.3.

  The EMU option will be investigated again utilizing the same consist and frequencies but amending the power car characteristics and redefining the overall train weights.

The present GO Transit policy is to limit the train size to 10 cars due primarily to the length of station platforms but also due to the amount of hotel power that can be supplied to trailing bi-levels by one F59PH locomotive. The Consultant, however, was also requested to simulate both the diesel and electric locomotive options with 12 bi-levels on the two lines selected for comparative purposes.

2.4 TRACTION SYSTEMS TO BE ADDRESSED

The electrical traction system to be evaluated in detail will be the 25kV ac overhead contact system. A technical comparison will be given both from previous studies and current technology between 1500V/3000V dc and the 25 kV ac system. Brief reference will be made to the 50 kV ac system. It is not cost effective in urban areas.

Details will be found in Section 9.

2.5 PROJECTED GO TRANSIT INFRASTRUCTURE

Normally, traffic projections are used as the basis to determine future infrastructure needs to support the future levels of ridership and, in this case, future levels of freight traffic to be handled in the common corridors.

The pre-feasibility nature of the study, the indefinite time horizon and the limited scope have precluded this approach. It was decided, in consultation with GO Transit, to utilize the CN Rail and CP Rail simulations in these corridors as the basis for cost estimation since these simulations have been based upon GO Transit growth estimates and confidential CN Rail and CP Rail tonnage and traffic patterns. The track layouts are shown in present and future formats in Appendix F.

2.6 OPERATING AND CAPITAL COST ESTIMATES

The operating costs will be analyzed on a variance basis. That is, operating cost items will be estimated and included in the economic analysis only if the item in question is variable between the options.

The capital costs will be estimated by making reasonable judgements as to the future requirements directly attributable to GO Transit electrification. For example, GO Transit will, in the future, be operating trains in corridors with up to 6 main tracks and the number of tracks to be electrified in this territory will need to be assessed from the viewpoints of both GO Transit (limit capital cost) and the other railways (flexibility of operation).

2.7 ECONOMIC ANALYSIS CRITERIA

The economic analysis will be based on a cost comparison of four operating scenarios which are described in detail in Section 13.

Scenario 1:	Dieselization of the entire system
Scenario 2:	Electric locomotives on the Lakeshore line and diesel locomotives on the branchlines

Scenario 3: Electric locomotives throughout the system

Scenario 4: Electric locomotives on the Lakeshore line and EMU cars on the branchlines.

The study horizon will span a period of 30 years from the present. All figures will be expressed in 1992 constant dollars, Canadian currency. The discount rate used is 3.75% which is the average real return to GO Transit over the past 20 year period. These, and other assumptions on which the economic analysis is based are discussed in detail in Section 14: Economic Analysis.

3.

REVIEW OF PREVIOUS STUDIES

3. REVIEW OF PREVIOUS STUDIES

This section will present a brief summary of results contained within other studies which have addressed the electrification of GO Transit Rail Services.

3.1 GO-ALRT

Electrification System Selection Study Report[1]
July 29, 1983

The GO-ALRT program was to provide commuter services in the Metropolitan Toronto area utilizing light rapid transit vehicles operating on dedicated track. Initially, the system was intended to supplement the existing GO Transit service on the Lakeshore by providing a service between Oakville and Hamilton in the west and Oshawa and Pickering in the east. Later developments were planned to provide a complete GO-ALRT service between Hamilton and Oshawa, along the Lakeshore. A northern link via Toronto International Airport and the city centres of North York and Scarborough was also envisioned.

Determination of the most suitable voltage for electrification of the GO-ALRT system was a fundamental design criterion and on April 19, 1983 Cole Sherman Transmark Inc. was retained to carry out a study into the selection of an electrification system.

Seven possible systems were analyzed. Of these, three were considered to be unsuitable for the GO-ALRT application and were eliminated from the evaluation. The remaining four systems, which were technically feasible, were subjected to a preliminary cost comparison which led to rejection of the 600/750 V dc system as much more costly than the others. The 3000 V dc system was also rejected on the grounds that traction motor installation design would be difficult, if not impossible.

A final comparison evaluation of the 25 kV and 1500 V dc systems indicated that there might be only marginal differences in cost between them. The study had, however, shown that a 1500 V dc system could be susceptible to overloading and

1 For list of references see Section 15

would be less reliable than the 25 kV system, given the performance and level of service demanded. Accordingly, it was recommended that 25 kV be adopted as the voltage for GO-ALRT(*).

3.2 GO TRANSIT LAKESHORE COMMUTER SERVICES
Assessment of System Expansion Alternatives[2]
July 30, 1982

The options which were selected for general consideration are listed below.

Option 1 - Diesel Locomotive Hauled Bi-Level Cars

Option 2 - Electric Locomotive Hauled Bi-Level Cars

Option 3 - Electric Multiple Units, Bi-Level Cars (EMU)

Option 4 - Advanced Light Rail Transit Vehicle (ALRT)

A Summary of Comparisons is presented below. It was presented within that report as Table 4.6 as reproduced below.

The viable alternatives in expanding GO Transit Services were proposed to be:

a) Continue to share tracks with the railways and provide additional track and signal facilities for conventional diesel or electric commuter trains. The railways would retain ownership of the right-of-way and operate the service. (Options 1 and 2 respectively)

b) Provide separate tracks for diesel or electric commuter trains on a separate right-of-way adjacent to the railway right-of-way, except in restricted areas where property would be purchased or leased from the railways for a shared right-of-way. Shared tracks would be limited to shared right-of-way locations where railway traffic would be minimal. GO Transit would own the facilities and operate its own service. (Option 3)

(*) Summary of Findings, GO-ALRT Study Report

COMPARISON FACTOR	SYSTEM OPTION			
	1	2	3	4
Quality of Service	Good	Good	Good	Good
Capital Costs	$1,416M	$1,560M	$1,621M	$1,568M
Annual Operating Costs	$86M	$66M	$69M	$42M
Environmental/Community Impact	least	least	highest	moderate
Energy Conservation	uses diesel fuel	electric power	electric power	electric power (efficient)
Operational Flexibility for GO Transit	limited control	limited control	improved control	full control
Staging Flexibility to Match Growth	possible	possible	limited	limited

c) Provide separate tracks for an intermediate capacity rapid transit service, using a light rail vehicle developed specifically for the corridor. The tracks would occupy a separate right-of-way adjacent to the railway right-of-way, except in restricted areas where property would be purchased or leased from the railways for elevated separate tracks. GO transit would own the facilities and operate the service. Vehicle structural standards and operating practices would conform to transit standards rather than those which apply to mainline railways. (Option 4)

3.3 TRANSIT ELECTRIFICATION

Bus and Rail[3]

Ministry of Transportation and Communications (Ontario)

April 1981

The following summary of relevant results has been condensed from Section 6.8 Summary of this report.

a) Route Analysis

There were no major impediments identified in any route segment, assuming a system voltage of 25 kV, 60 Hz.

Significantly more main-line trackage would have to be electrified to suit existing operational practices and procedures than would in fact be needed by GO Transit for an independent route.

b) Technical Review and System Selection

The geographic nature and gradient profile of the routes, together with the train weight and acceleration requirements are such that the 25 kv, 60 Hz centre-feed system proved to be the natural choice for the electrical system.

Vertical clearances through Union Station are not sufficient for 25 kV operation.

c) Phased Introduction of Electrified Service

It was suggested that the Lakeshore route from Oakville to Pickering would form a natural first phase since it has a high ridership and (at that time) was the only route operating throughout the normal travel day.

d) Coordination of User Requirements

This study approached the coordination question from the point of view that VIA, CP Rail and CN Rail would electrify and integrate within an overall electrified railway infrastructure. It was felt that the inclusion of VIA could be accomplished by possibly electrifying some additional trackage while the inclusion of the two major railways might involve heavier catenary, additional substations, an increase in system voltage or a combination of the preceding.

The capital costs for Phases I and II were estimated at $206.153M. The net saving in operating costs due to electrification varied between $683,000 and $834,000 annually.

3.4 ONTARIO RAIL ELECTRIFICATION: A BRIEF EXAMINATION

Canadian Institute of Guided Ground Transport[4]

July 1980

The following summary of results has been condensed from Section 4.7 of that report.

The most promising section was considered to be the section between Oakville and Pickering.

The study estimated the net savings in annual operating costs to be $3.476M and the net total capital required to be $52.690M for the stated Lakeshore line.

The study considered that the electrification of GO Phase II (other branchlines) would not be financially attractive given the traffic densities at that time.

In this case there would be no net operating cost saving but there would be a net additional capital outlay of $61.529M.

3.5 ELECTRIFICATION OF GO TRANSIT RAIL SERVICES

Electrack Inc.[5]

June 1980

The following summary has been taken from the Executive Summary of this report.

The study was divided into two phases. Phase I consisted of a medium level assessment of the Lakeshore route between Oakville and Pickering on the basis of the existing 20 minute peak period frequency and maximum trip time of 80 minutes, but with provision for future expansion of service to a 10 minute peak period frequency.

Phase II consisted of a low-level assessment of the routes to Richmond Hill, Georgetown and Milton with a review of the extension from Milton to Guelph Jct.

The Phase I capital costs were estimated at $80.8M. The Phase II costs were estimated at $168.1M. Capital costs for Signals/Communications, Clearances, Locomotives and Bi-Level Cars were not derived. No costs were included for the following:

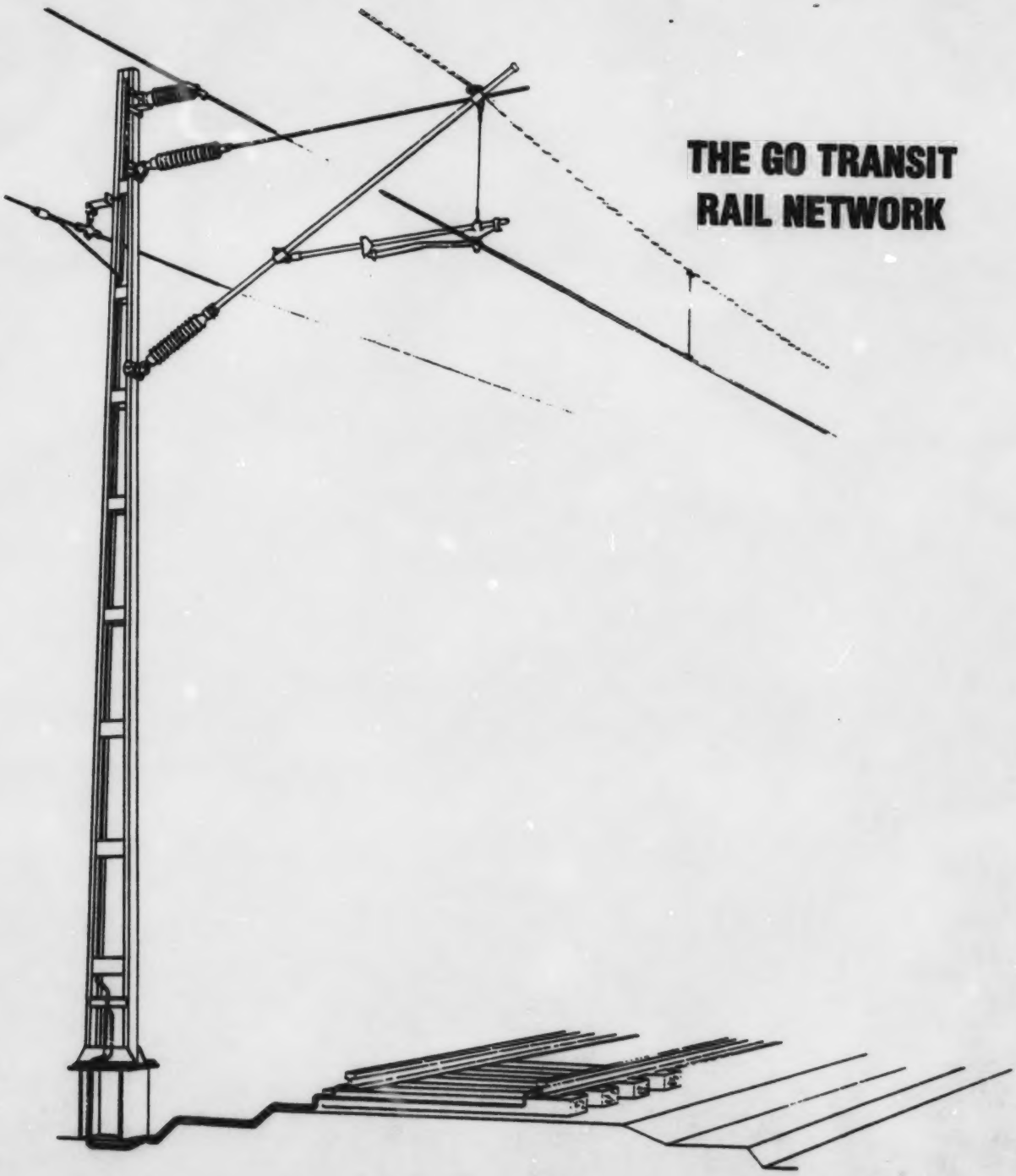
- reorganization of maintenance practices to accommodate electrification;
- electrical interference upon local utility circuits;
- railway surcharges for rerouting during construction;
- railway operating costs applicable to construction trains;
- agency costs.

The study confirmed the technical feasibility of electrifying the GO Transit Rail Services, provisionally at a voltage of 25 kV, 60 Hz. The nature of the commuter services and their routes are such that all routes from Toronto could be served by a single major substation near Union Station. If electric service were to be extended from Oakville to Hamilton a second substation would be needed in the Burlington area.

Phase I (Lakeshore line) would be the first step for introduction of electrified service. The introduction to other branches would be appropriate if service were expanded to all-day regular interval format given the purchase of additional passenger cars and locomotives.

4.

THE GO TRANSIT RAIL NETWORK



CPCS Ltd. in association with Hatch Associates Ltd.

4. THE GO TRANSIT RAIL NETWORK

4.1 THE PRESENT AND PLANNED RAIL NETWORK

GO Transit began as a three-year experiment in May 1967 with a single rail line along Lake Ontario. GO Train service is now a six-corridor network, connecting with GO Buses, local transit and the extensive Toronto Transit Commission (TTC) system.

The original rail system added the Georgetown line in 1974, the Richmond Hill line in 1978, the Milton line in 1981 and the Stouffville and Bradford lines (which GO acquired after abandonment by VIA Rail) in 1982.

GO Transit Rail Summary

Stations		51
Route	- Kilometres	426
	- Miles	266
Train trips daily		152
Passengers daily, May '91		91,000
Bi-Level Coaches		331
Locomotives		49

Figure 4.1 presents the rail service as it currently exists as well the potential expanded future service.

The following Table 4.1 summarizes the network extensions that GO Transit anticipates given continuing growth in the Metropolitan Toronto area and accelerating demand for public transportation.

TABLE 4.1

LINE	PROPOSED EXTENSIONS
Lakeshore West	Hamilton (Burlington full service)
Lakeshore East	(full service Oshawa)
Guelph	(full service to Georgetown)
Barrie	(full service to Bradford)
Richmond Hill	Vandorf (full service to Richmond Hill)
Stouffville	Goodwood (full service to Stouffville)
Milton	(full service to Milton)

This study will address the electrification cost estimates of the GO Transit rail network based upon the trackage layouts shown in Appendix F. The information regarding extensions is mentioned for completeness and to update readers unfamiliar with the GO Transit service expansion plans.

4.2 PLANNED CAPACITY INCREASES

The planned capacity increases by GO Transit can be addressed in the medium term (for which decision making criteria are reasonably stable) and in the long term (for which decision making criteria are uncertain).

In the medium term, GO Transit plans the following capacity increases:

- Expansion of Lakeshore West service to existing Burlington GO station;
- Expansion of Lakeshore East service to existing Oshawa station;
- Provision of additional track capacity on Lakeshore East to allow for increased peak period service on the Lakeshore East and Stouffville lines;
- Expansion of Milton service to Milton;

Figure 4.1
EXISTING AND POTENTIAL RAIL SERVICE

CPCS Ltd. in association with Hatch Associates Ltd.

- Expanded peak period services on Richmond Hill, Stouffville and Bradford corridors;
- Extension of Richmond Hill service northerly to Vandorf.

In the long term, GO Transit plans the following capacity increases:

- Expansion of the Stouffville service consistent with demand;
- Expansion of the Georgetown service consistent with demand;
- Expansion of the Richmond Hill service consistent with demand;
- Enhancement of peak and off-peak service on the Lakeshore West;
- Expanded peak period services on Bradford line consistent with the demand;
- Expansion of peak service to Hamilton.

The information contained within this section has been used to develop the Estimated OCS Costs in Section 9.6 and to select the four Scenarios as outlined in Section 13.1.

4.3 PLANNED SERVICE ENHANCEMENTS

Planned service enhancements are defined to be amendments to the GO Transit service which will, without some intervention upon the part of GO Transit, impact upon GO Transit's ability to provide improved commuter rail services to the public.

Two major enhancements have been brought to the attention of the Consultant during the survey phase of this study:

- Access for the physically disabled to GO Transit Rail Services; and
- Additional Stations on the network.

GO Transit is presently involved in a modification program of the fleet of bi-level coaches in order to make them accessible to the physically disabled. GO Transit is targeting to have its entire network accessible for the physically disabled by the year

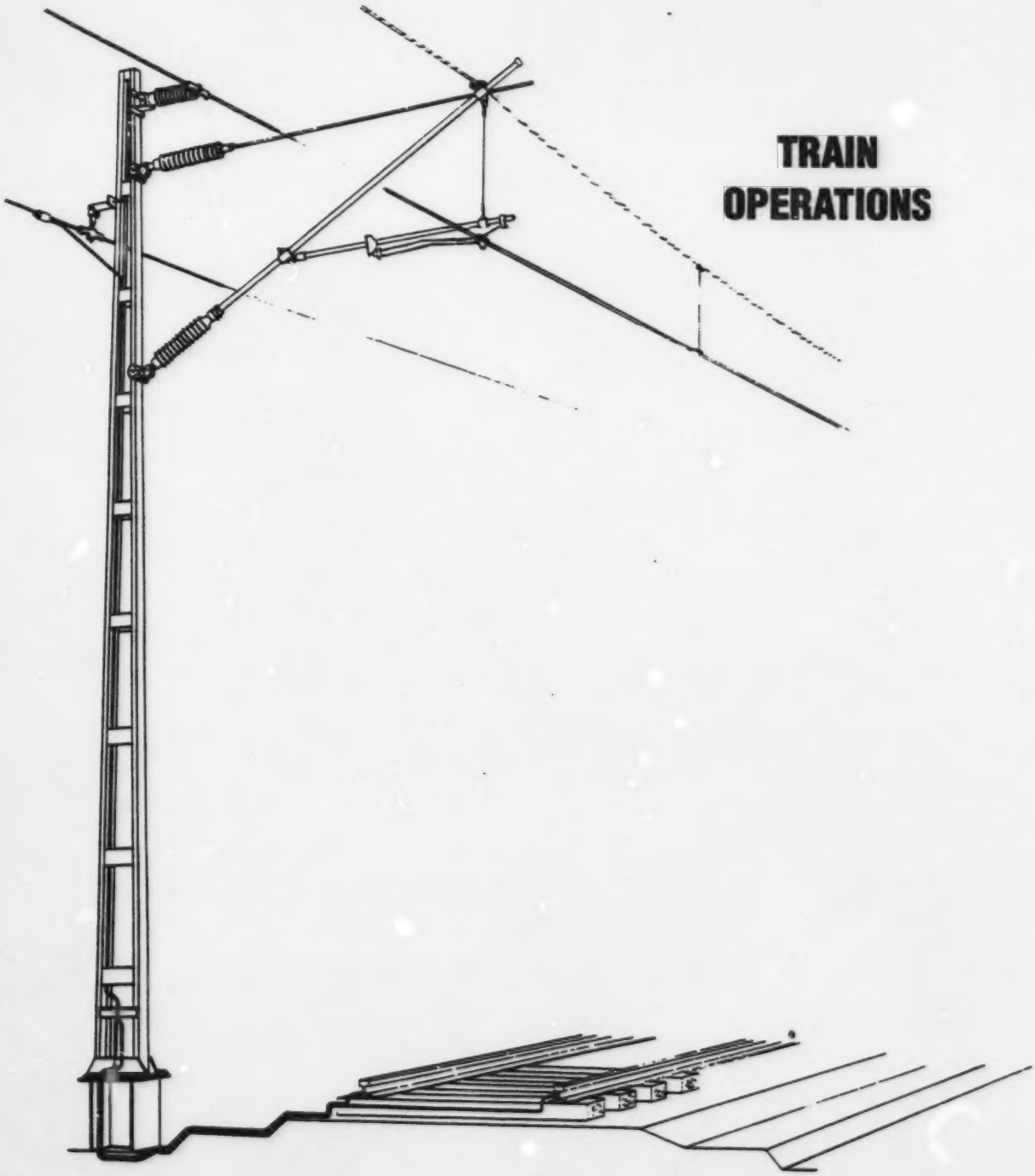
1993. This policy could result in additional dwell time at many stations and without proper handling could lengthen GO Transit's schedules.

Several projects and studies have been completed (or are underway) of late which address the integration of the entire public transportation infrastructure within the Metropolitan Toronto Area.

Both of these planned service enhancements will impact GO Transit's operational policy. Section 8 will more fully investigate the ability of both diesel and electrification to accommodate the impacts of these enhancements. Section 8 will simulate increased dwell times and additional stations and will compare these simulations on the bases of fuel/energy consumption and overall journey times.

5.

TRAIN OPERATIONS



5. TRAIN OPERATIONS

5.1 TRAIN OPERATION PATTERNS

This section will summarize the train operation patterns of GO Transit Rail services provided during regular Monday-Friday service.

5.1.1 Lakeshore Line

Between Hamilton and Oakville, GO Transit provides three trains in the morning peak eastbound and three trains in the afternoon peak westbound.

Between Whitby and Oshawa, GO Transit provides one train in the morning peak westbound and one train in the afternoon peak eastbound.

Between Whitby and Oakville, GO Transit provides basically a 20 minute service augmented to 10 minutes for critical periods in both the morning and afternoon peaks and hourly service for the remainder of the operating day.

5.1.2 Milton Line

The eastbound service from Milton offers five trains in the morning peak and one train in the afternoon peak. The westbound service from Toronto offers five trains in the afternoon peak and one evening train.

5.1.3 Georgetown Line

Between Guelph and Georgetown, the eastbound service consists of one train in the morning peak and the westbound service consists of one train in the afternoon peak.

Between Georgetown and Toronto, the eastbound service offers four trains in the morning peak and four trains in the westbound evening peak. There is no rail service during the off-peak period.

5.1.4 Barrie Line

The service on this line consists of one train in the morning peak southbound and one train in the evening peak northbound that operate through from Toronto to Barrie with intermediate station service. There is no off-peak service on this line.

5.1.5 Richmond Hill Line

The service on this line is limited to the morning and evening peaks. Southbound in the morning four trains operate. Northbound in the evening four trains also operate. There is no off-peak service on this line.

5.1.6 Stouffville Line

This line offers two trains southbound in the morning and two trains northbound in the evening. There is no off-peak service on this line.

5.1.7 Saturday, Sunday and Holiday Service

The Lakeshore line offers hourly service eastbound from Oakville to Whitby between 0630 and 2330. Westbound service commences at 0546 and continues hourly until 2346. There is no service between Hamilton and Oakville nor Whitby and Oshawa.

The remaining 5 lines do not offer Saturday, Sunday or holiday train service.

5.2 SHARED TRACK USAGE (CN/CP/GO)

As can be established from the previous section 5.1 the Lakeshore line is the only major CN line on which GO Transit currently offers a full service train schedule. The Consultant reviewed the available information from CN Rail regarding the anticipated freight traffic volumes and train patterns on this line. It was stated by CN Rail that the simulations which generated the proposed track layouts as shown in Appendix F will handle both freight and GO Transit commuter traffic efficiently with/without electrification.

The medium and long term plans on the other branchlines for full service would indicate that there will be no ramifications on either of the major railroads. Even under the assumption of full service it is doubtful whether there will be any problem areas given the low levels of freight traffic on these lines.

Under the electrification scenario of GO Transit, whether introduced in stages or wholly, the railways CP, VIA, Amtrak, ONR and CN will have to be involved from the outset since electrified and non-electrified trains will be operated in these corridors at the same time. It will be necessary to examine all the operating rules and general instructions for each of the railways in order to ensure the safety of personnel and property under any eventuality.

The impact of the OCS system upon the methods used by CN Rail and CP Rail to facilitate track maintenance and derailment clearing must be investigated given that the OCS will restrict the unencumbered use of certain types of on and off-track machinery such as cranes.

Another issue that must be addressed is the incorporation of the electrification control systems with the train operations control systems on these corridors so that information flow is instantaneous between the two functions.

Each of these operational issues will require significant amounts of planning in order to satisfy the railways and the regulatory bodies that the electrification of GO Transit will not detract from the prevailing levels of safety and confidence.

5.3 BENEFITS/DRAWBACKS OF DIESEL VERSUS ELECTRIFICATION

This sub-section presents a brief outline of the benefits and drawbacks of diesel and electric train operation. While the listing is not exhaustive, it is meant to convey to the reader the major comparisons often made between these two operating regimes and are shown in decreasing order of significance.

Each of these items will be discussed in further detail throughout the report in the appropriate context.

5.3.1 Benefits of Diesel Operation

- Unlimited choice of routes and assignment;
- Compatibility/interchangeability with other railway equipment in the corridors;
- Technical breakdown confined to one train.

5.3.2 Drawbacks of Diesel Operation

- Diesel engine servicing and overhauls;
- Noise, fumes, oil and fuel dispersion;
- Per unit horsepower limitation;
- Slow acceleration to top speed;
- Non revenue movements required for refuelling at specific points;
- Shorter economic life;
- Limited categories of usable fuel;
- Powerful cleaning agents required to remove oily residue.

5.3.3 Benefits of Electrified Operation

- Reduced maintenance cost and associated time;
- Choice of primary energy source (via electricity);
- Fumes and oil dispersion eliminated;
- Reduced noise at layover sites;
- Reduced train noise;
- Greater per unit horsepower and acceleration;
- Shorter headways;
- Greater energy efficiency; at source generators; partial recovery of braking energy;
- Overtrack property development;
- Ample hotel and standby power available via locomotive, with minimal standby maintenance.

5.3.4 Drawbacks to Electrified Operation

- Locomotives and power cars confined to electrified areas;
- Clearance envelope expanded;

- Replacement of incompatible track circuits and signalling systems;
- Increased public utility peak electrical load;
- Maintenance of OCS;
- Train immobilization due to OCS damage;
- Shielding or replacement of incompatible communication cables;
- Supplementary operating and safety rules;
- Accidental damage to OCS;
- Reduced mobility for on-track cranes;
- Visual intrusion of OCS.

5.3.5 Benefits of EMU over loco hauled train

- Train can be sized to suit passenger loading: Energy consumption roughly proportional to train size for consistent service speeds.
- Frequent off-peak service can be maintained while most of rolling stock is receiving services at workshops; and at low energy cost (see Section 8.6.4).
- Very high power to weight ratios can be built in.

5.3.6 Drawbacks of EMU

- More motor power equipment to inspect/maintain.
- Total inspection time for passenger cars increased requiring either more inspection/maintenance trackage inside workshops or more manpower.

6.

ROLLING STOCK

6. ROLLING STOCK

6.1 DESCRIPTION OF TRAIN CONSISTS

The base case for comparative analysis in this report is the F59PH diesel locomotive hauling ten bi-level cars. To simulate an electric locomotive hauled consist, the diesel is replaced by the new ALP44 class of locomotive used by New Jersey Transit (an upgraded version of the Amtrak AEM-7). To simulate some of the theory and practice of EMU operation, a relatively high powered European EMU is represented (see Appendix A - Locomotive and EMU data). Some notes on bi-level EMU's are given in Section 6.3.1 and further notes on European standards in Section 6.2.

As noted in Section 1.2.1, development of GTO's and induction traction motor controls within the past decade have increased the practicality of power regeneration during train braking on ac systems. Evaluation is still ongoing but for the purposes of this study the Consultant has estimated a possible electrical (OCS) recovery of 50 percent of the theoretical braking energy (see Section 8.8.1). This recovery is further evaluated as a "regeneration" option in the energy and cost analyses. The energy is expected to be consumed by other trains. It is not envisioned as a reverse flow into the public utility. The ALP44 class of locomotive does not have regeneration capability.

For further details regarding train consists and simulations refer to Sections 8.3.1 and 8.3.2.

6.2 COMPARISON OF NORTH AMERICAN VERSUS EUROPEAN DESIGN CRITERIA

This section is intended to highlight the differences and similarities between equipments used on general purpose (or standard) railways in North America and Europe in view of the mutual interest in electrification development and technology interchanges. Exceptions will be found.

6.2.1 Track Gauge

Nominally the same. Differences in wheel and rail profiles may affect high speed performance.

6.2.2 Rolling Stock Dimensions

Width: - similar. North American may be a few centimetres wider.

Length: - similar. A function of width, track curvatures and turnout (switch point) angles.

Height: - the most visible difference: North American passenger cars typically 60 cm higher. European height has traditionally been constrained by numerous tunnels and overpasses which have only been adjusted to suit electrification clearance. Thus, European catenary may be 5.5 m above rail whereas the optimum for North American freight is 7.0 m.

Strength: - the mandatory end-strength (crushing strength) of North American cars is much higher than most European rolling stock. This precludes the commercial use of standard European vehicles on North American freight trackage.

Weight: - strength considerations have generally resulted in heavier North American passenger cars which, for equal locomotive or EMU motor power, results in lower rates of train acceleration than for European trains.

6.2.3 Electrical Power Supply

As noted in Section 1.2, modern traction control and motor design is similar in North America and Europe. The same nominal dc and ac supply voltages can be found, up to 25 kV ac (50 kV locomotives are not used in Europe). Actual interchange of demonstration vehicles requires verification and modification of frequency dependent components of ac powered units. For 25 kV ac systems this represents a frequency change from 50 to 60 hertz.

6.3 GO TRANSIT ROLLING STOCK CONVERSION

6.3.1 Bi-Level Cars

The possibility of converting bi-level cars into self-propelled EMU trains has been investigated.

Bi-level passenger cars were developed to provide maximum seating and good passenger entry/exit flow within conventional rolling stock dimensions. The most significant design feature is the drop floor (or well) construction between the trucks. This permits an upper floor level to be added over the well. Each end of the coach has a conventional floor level over the truck with space above the ceiling for apparatus such as air-conditioning, ventilation and battery chargers. This apparatus can be serviced through ceiling panels and withdrawn up through a large roof hatch. Half of one end of each car is used for a lavatory or a drivers cab.

Trucks carry the body via large air springs each side of the body. The body centre sill deepens (drops) over outer and inner truck axles to form the draft sill and body well respectively.

Traditional EMU construction based on passenger cars (see Appendices A-3b, A-3c) involved hanging most electric traction equipment below the floor between the trucks. Trucks themselves were motorized by motors resting on each axle (axle-hung). Some resistors and ventilation equipment might be put on the roof or in the ceiling. With overhead catenary supply a pantograph and circuit breaker or disconnecter would also be put on the roof.

The well-style of the bi-level coach leaves no underfloor space for traction equipment. In addition, the GO cars leave very little space for traction motors.

One of the successful features of modern EMU traction equipment is modular construction designed for quick exchange on roll out trays and forklift transfer. Thus low side access is the first choice location. For GO cars this would involve intrusion

into the lower passenger floor or traction equipment would be placed in each end of the car, above the trucks making use of roof hatches and high side access panels.

Enquiries have been made of those close to the original body and truck design for GO cars and no evidence has been found of any electrification conversion being achieved on the drawing board in spite of it often occurring in conversation. The Consultant considers that the car design is efficient and harmonious for its current purpose but conversely is not suited to "conversion" to an EMU traction power car. Specifically because of structural changes needed and/or maintenance difficulties and very limited traction motor space. The last meaning low horsepower and a completely new design of truck.

The only "conversion" scenario suggested here, and in later economic comparisons, is the purchase of new driving motorized cars to be paired up one-plus-one with existing bi-levels. The new motor-cars would be built to harmonize with existing cars but sacrifice some seating to structural differences over the trucks and in the lower body sides. Assume a 40 seat loss. All four axles of the motor-car are assumed to be motorized up to modern motor design horsepower for EMU's.

6.3.2 Locomotives

The GM F59PH locomotives are of modern design specifically for commuter service. They could also handle fast freight if assigned in consist with like locomotives.

The quantity production of diesel-electric locomotives in North America renders them relatively cheap compared with modern electric locomotives in North America (less than half the cost; however the cost per available rail horsepower is similar).

Although it is possible to create a dual-mode locomotive, with reduced power in both modes, such a locomotive has no obvious use at this time except for certain specialized train yard and work train functions. Either dual mode or total conversion of modern diesel-electric locomotives is not recommended as long as there is a useful role for the standard locomotive. And whether or not components can be

sold, the remaining frame would have little if any cost advantage for re-fitting to mount electric locomotive components.

For any proposed electric locomotive operation the most appropriate modern specifications should be used to acquire new equipment.

Because GO Transit is a coherent operating system with relatively new equipment and several routes, any electrification must be a phased-in process and some diesel operation is likely to remain for the foreseeable future. Thus if part of the electrification equipment represents new growth and part of the diesel equipment is leased out or sold in good order, then there is no likely benefit from any equipment conversion except to yield a few special service or test vehicles.

6.4 LOCOMOTIVE HORSEPOWER

Most electrification studies and developments in North America in recent decades have either considered or actually used European locomotive components. This has led to a mixture of European and North American standards and/or convention in defining locomotive power ("horsepower") and the relative power of electric and diesel-electric locomotives.

The quoted power of a North American diesel-electric locomotive is the horsepower delivered by the diesel engine into the main generator. The rated power available at the wheels varies with operating circumstances but averages about 84% of the generator input horsepower.

By European convention electric locomotive power is quoted at the wheels as rail kilowatts (where 0.746 kilowatts equals one horsepower).

In North America electric locomotive power may be quoted as the shaft/generator power needed if it had been powered by a diesel engine.

As a comparison the following results:

3000 HP diesel equals 2500 rail HP or 1860 rail kW
6000 HP diesel equals 5000 rail HP or 3720 rail kW

For train performance calculations, precision is achieved by always working from performance curves of actual locomotive tractive effort versus speed. The only adjustment needed is to include the locomotive weight in calculations of acceleration and hill climbing.

A modified convention will often be seen in defining the power and performance of EMU trains. The EMU represents a fixed allocation of motive power to a fixed unit length (and weight) of train; with due allowance for passengers.

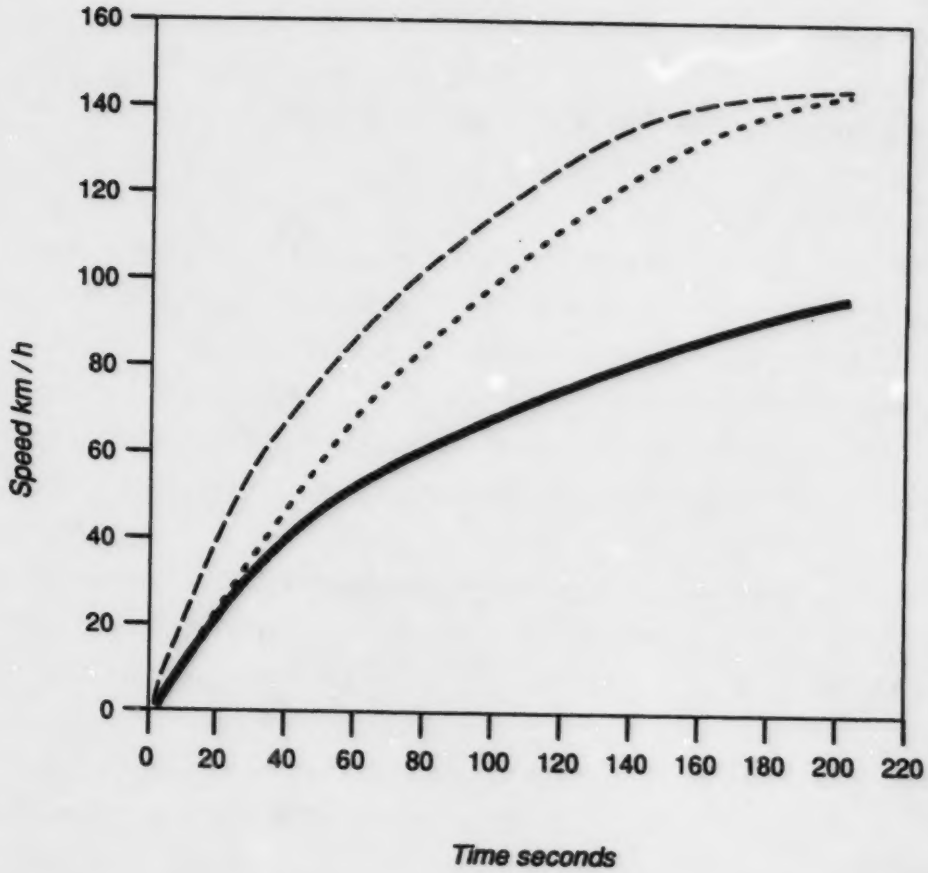
Performance may be specified as average acceleration rate up to design speed, on assumed level track. Power may be expressed as the horsepower (or kilowatts) of the traction motors. This specification of acceleration (and usually braking deceleration) permits quick graphical assessments of train performance station to station, the traditional technique before general use of computer calculated simulations.

Figure 6.1 presents a comparison of the acceleration curves for the 59PH-Diesel, the ALP44 electric locomotive and 5-X10 EMU's with an effective trailing load of 700 t.

At slow speeds the true power developed (and power consumed) by any locomotive or EMU is limited by tractive effort possible before wheels slip on the rail. Although tractive effort is maximized by the motor control system (typically 20% up to 30% of axle weight on each driver axle) the true power is always the product of tractive effort times speed. At the moment of starting the true rail power is zero; all consumed power is flowing into auxiliary machinery and electrical losses causing heat.

Typically, tractive effort is nearly constant up to the design "horsepower" limit. Then tractive effort falls in inverse proportion to rising speed.

Figure 6.1
COMPARISON OF ACCELERATION CURVES
Effective Trailling Load 700t



F59PH

ALP44

5 - X 10 EMU's

In practice, with normal adhesion between wheels and rails, the maximum continuous tractive effort of the locomotive is limited by motor heating offset by motor cooling design. (Excess heating is cumulative leading to temperature rise and ultimately burning of insulation). The motor has a design continuous tractive effort, with a slightly higher figure quoted for 1 hour and substantially higher ratings from 15 minutes down to one minute.

This becomes very significant in the accelerate-coast-decelerate workings of suburban passenger trains.

Most electrical devices have short-term or "overload" characteristics. This leads to one of the most significant practical differences between electric and diesel-electric trains. Both use traction motors and can theoretically create the same initial high tractive effort per axle weight. (In practice electrics achieve slightly better adhesion control). But for short duration runs the electric can "overload" the entire motor power supply system whereas the diesel engine horsepower is set to a fixed limit.

This means that in short trips the effective "horsepower" of an electric locomotive or EMU is substantially greater than the estimated diesel-equivalent horsepower and thus they achieve quicker start to stop runs than the diesel powered train.

In summary, the distinctions between electric and diesel-electric locomotives working suburban passenger trains, when considering locomotives of similar size and weight, are:

1) the electric locomotive can be designed for at least twice the equivalent continuous horsepower of a diesel;

2) the horsepower available when accelerating an electric train is greater than its continuous horsepower.

6.5 ROLLING STOCK COST ESTIMATES

Further to sections 6.1 and 6.3 above and based on reported equipment prices, Table 6.1 estimates the following rolling stock costs, expressed as 1991 Canadian dollars.

TABLE 6.1

	$ millions	Seats	$/Seat thousands	DE H.P.	$/DE H.P. thousands
Diesel locomotive	2.5	1,620	10.8*	3,000	0.8
Electric locomotive	5.5-6.5	1,620	12.6-13.3*	6,960	0.8-0.9
GO bi-level car Motor coach to suit above (EMU paired one plus one)	1.5 2.5	162 122	14.1	1,830	1.4
3-car EMU, European	4.5-6.2	290	15.5-21.4	1,830	2.5-3.4
2-car EMU - European	3.1-4.8	190	16.3-25.3	1,830	1.7-2.6

*Includes cost of ten bi-levels.

In Table 6.1 above, costs have been extended to reflect cost per diesel equivalent (DE) horsepower and cost per passenger seat on the basis of all new equipment purchases. The conceptual GO EMU uses one motor coach paired with one bi-level. The European EMU represents total cost of a typical multi-door single level EMU built to European strength/weight/power standards.

6.6 CHARACTERISTICS OF ELECTRIC LOCOMOTIVE AND EMU MAINTENANCE

A good estimate of electric locomotive maintenance requirements and costs can be made by examining the components of a diesel-electric locomotive and the conventional and/or mandatory inspection and service intervals.

Labour costs for routine inspections (daily and up) represent a substantial unavoidable annual total. The diesel engine accounts for most maintenance cost differences, diesel versus electric. The electric locomotive transformer has very low maintenance costs. Pantograph wear requires frequent observation like brakeshoe wear but does not significantly inflate the aggregate frequent inspection costs. The infrequent (typically 5-10 years) but heavy "backshop" costs associated with the diesel engine are avoided with electrics.

Considering electric and diesel locomotives of similar physical configuration and weight, annual costs could be weighted as shown in Table 6.2 below:

TABLE 6.2

Relative Maintenance Cost Indices

Task	Electric			Diesel		
	Labour	Material	Total	Labour	Material	Total
Daily Inspection	10	10	20	14	12	26
Other, Scheduled	3.4	0.6	4	5.5	2.5	8
			24			34
Unscheduled repairs & service			24/36			40
Backshopping			2/6			26
			50/66			100

The variance shown in the above table is intended to reflect maintenance skill and design experience in unscheduled repairs and the extent to which "backshopping" work may be accomplished in regular (e.g. annual) maintenance.

To attempt cost comparison in any greater detail requires knowledge of relative operating conditions and the adopted mix of maintenance policies defining mileage dependent and time dependent (datal) component maintenance schedules.

Using the GO Transit 1990/1991 Equipment Maintenance Breakdown of Costs as a guide to maintenance activity, with locomotive and coach supervision and overhead prorated, projected electrification savings per locomotive range from $60,000 to $90,000 annually.

Total maintenance savings would be further increased when the useful horsepower advantage of electric locomotives can be used to reduce the overall fleet size. On an equal horsepower basis, total electric maintenance cost falls to 33-25% of diesel locomotive maintenance.

Estimates for Coach and EMU maintenance are derived in Section 13.4.

6.7 MAINTENANCE WORKSHOPS

Willowbrook shops have evolved as a well integrated well managed running maintenance operation for both diesel-electric locomotives and passenger cars.

The objective has been to service or changeout all components up to main diesel engine/generator removal. The latter work is sent out; typically to CNR or ONR shops. It has also been found effective to contract out such work as motor overhaul, wheelset turning and airbrake component overhaul.

The shop is planned to perform all routine maintenance according to scheduled mileage (or time) intervals and to rectify most unscheduled repairs with minimum equipment delay.

Shop layout reflects the scheduled work and provision for unscheduled repairs.

Upon completion of current expansion plans the shop site will be fully and quite densely committed. In fact any further attempts at development would probably be congestive and reduce existing efficiency.

In the context of electrification, Willowbrook has specific but limited capability. It should remain the first-choice shop for diesels for the foreseeable future. It could receive the first electric locomotives. An additional single high level platform on inspection track 5B similar to track 5E would be useful for pantograph and roof equipment inspections.

At this stage, the diesel shop would not be "electrified". A diesel shop-switcher (or any external locomotive) would place the electrics for inspection.

EMU's require ground-level and underfloor inspection of power equipment and motors located every two or three coaches. Thus, it is desirable to have several "train-length" inspection pits. In this context Willowbrook could handle a few EMU's but is not suited to EMU fleet growth.

Willowbrook stores has some space for new electric rolling stock shelf items but is limited for complete maintenance spares for electric or any other new distinct class of locomotive.

Thus, although Willowbrook could play a useful role from the very earliest stages of electrification and, for example, in a demonstration project, it is recommended that developing another site be seriously considered in the electrification context. It is recommended that plans for such a site leave open the possibility of complete electric locomotive servicing and/or provision for EMU servicing. Diesel facilities have attracted public environmental anxieties, many of which would be absent from electrification development. These include diesel engine noise, fumes, fuel storage and fuel transportation.

7.

ENVIRONMENTAL CONSIDERATIONS

7. ENVIRONMENTAL CONSIDERATIONS

This section provides a review of the environmental considerations associated with the electrification of the GO Rail system.

7.1 ENVIRONMENTAL ASSESSMENT

Any proposal to electrify the GO Rail System, due to its scope and nature will likely have to undergo environmental assessment, under both Provincial and Federal requirements. The definition of environment, under assessment legislation, is very broad and includes air, land, water, plant & animal life, social, economic and cultural conditions, structures, sound, vibration, etc., and their interrelationships. Environmental assessment is essentially a very detailed planning exercise for predicting the potential environmental consequences of proposed undertakings.

7.2 ENVIRONMENTAL IMPACTS

Electrification of the GO Rail system will have some environmental implications, both positive and negative during each of the three stages (Stage 1 - Site Investigation, Stage 2 - Construction, Stage 3 - Operation and Maintenance) of the undertaking. These impacts are briefly reviewed under the broad categories of the natural and social environments. Both these environments will be affected to varying degrees by activities in each project stage. Table 7.1 summarizes areas of these environments that may be affected by electrification. This table distinguishes between positive and negative impacts.

It is assumed, for the purpose of this review, that the major activities associated with each project phase will be as follows:

- Stage 1 Environmental Assessment
  Feasibility Studies, Investigations
  Preliminary Design
  Design of System

TABLE 7.1

Potential Environmental Impacts of Railroad Electrification

ENVIRONMENT	Stage 1 Site Investigation		Stage 2 Construction		Stage 3 Operation & Maintenance	
	Pos	Neg	Pos	Neg	Pos	Neg
Natural Environment						
• Air Quality		○		○	■	
• Geological Systems				○		
• Vegetation				○	○	
• Water Resources & Fisheries		○		●	●	
• Wildlife				○	○	
Social Environment						
• Community Effects				●		○
• Economic Considerations	○		■		●	
• Noise		○		●	●	
• Visual		○		●		■
• Safety				○		●
• Electromagnetic Effects						●

○ Minimal impact
● Minor impact
■ Potentially significant impact

- Stage 2 Installation of catenary, transformers, switchgear
  Track lowering, bridge raising
  Improvement of signals and communications
  Raising of roof at Union Station
  Purchase of equipment including locomotives
- Stage 3 Operation and maintenance of system

7.2.1 Stage 1 - Site Investigation and Studies

Field work such as surveying, geotechnical investigations, soil sampling, etc., will be carried out during the study and design phases of the project. These activities are short-term in nature and generally do not have a significant effect on the environment.

7.2.2 Stage 2 - Construction

Construction of the railway electrification system should generally not have a significant impact on natural or social systems or on safety. The work which would be primarily confined to the railway corridors would cause some temporary adverse noise, traffic and visual impacts. Some disruption of service to both railway operations and to road traffic (at over-bridges that may need to be raised) will occur.

Even at Union Station, where the track shed roof may have to be replaced to obtain sufficient clearance, careful planning and staging of the work should minimize disruption and assure the safety of both the public and railway employees.

Significant economic benefits would accrue to Ontario based and other Canadian industries that would supply the bulk of material, equipment and labour required for the electrification program.

7.2.3 Stage 3 - Operation and Maintenance

7.2.3.1 Natural Environment

Air Quality

The following quote from the report of the European Conference of Ministers of Transport meeting of November 1989 is a clear endorsement for European railway electrification. "If the primary energy source is not coal or oil, then the benefits of using (electrical) railways are very considerable as regards to pollution of all types. The fact that there is at present great concern about the green house effect due to CO_2 and the problem of acid rain caused by NO_x emissions reinforces the advantages of electrified railways (but may pose the problem of nuclear energy in new terms)." The situation in North America may not be as clear.

Railways are a relatively small contributor to air pollution. Surveys have indicated that railroad emissions in the USA account for only about 1% of the total natural air pollutant emissions. The situation in Canada is expected to be similar.

This study has attempted to quantify and compare emissions as they would apply to both diesel and electric trains operating in the GO Rail system.

The two operating scenarios which form the basis of emission calculations are detailed in Section 13 of the report and described briefly below.

- Scenario 1 - all diesel operation at increased level of service. total annual diesel fuel consumption of 80.1 million litres.
- Scenario 3 - all electric trains with service levels as per Scenario 1. Total annual electrical consumption of 334 GWh.

Data for utility-generated emissions were provided by Ontario Hydro based on the assumption that all incremental electrical energy would be generated by coal fired plant. SO_x and NO_x incremental emissions are zero, reflecting Ontario Hydro's operation to Regulation No. 281/87 under the Environmental Protection Act.

Diesel emissions were calculated from data provided by CN Rail and data from the US EPA Report No. AP-42 "Compilation of Air Pollutant Emission Factors".

Emissions from diesel and electric GO Rail operations are compared in Figure 7.1 which clearly shows a definite improvement, following electrification, in all factors.

In terms of air emissions, another advantage of railroad electrification is that pollutants are transferred from the urban rail corridor setting to the stationary, sometimes remote generation facility where air emissions can be better controlled.

Electrification should produce tangible air quality benefits at rail yards and at railway stations, where the idling diesel locomotive is a source of particulate and hydrocarbon vapour emissions. These emissions are annoying to local residents (near rail yards) and to passengers and are a health concern. Hydrocarbon emissions, which contain toxic aromatic and polyaromatic hydrocarbons, are suspected carcinogens and may be of particular concern.

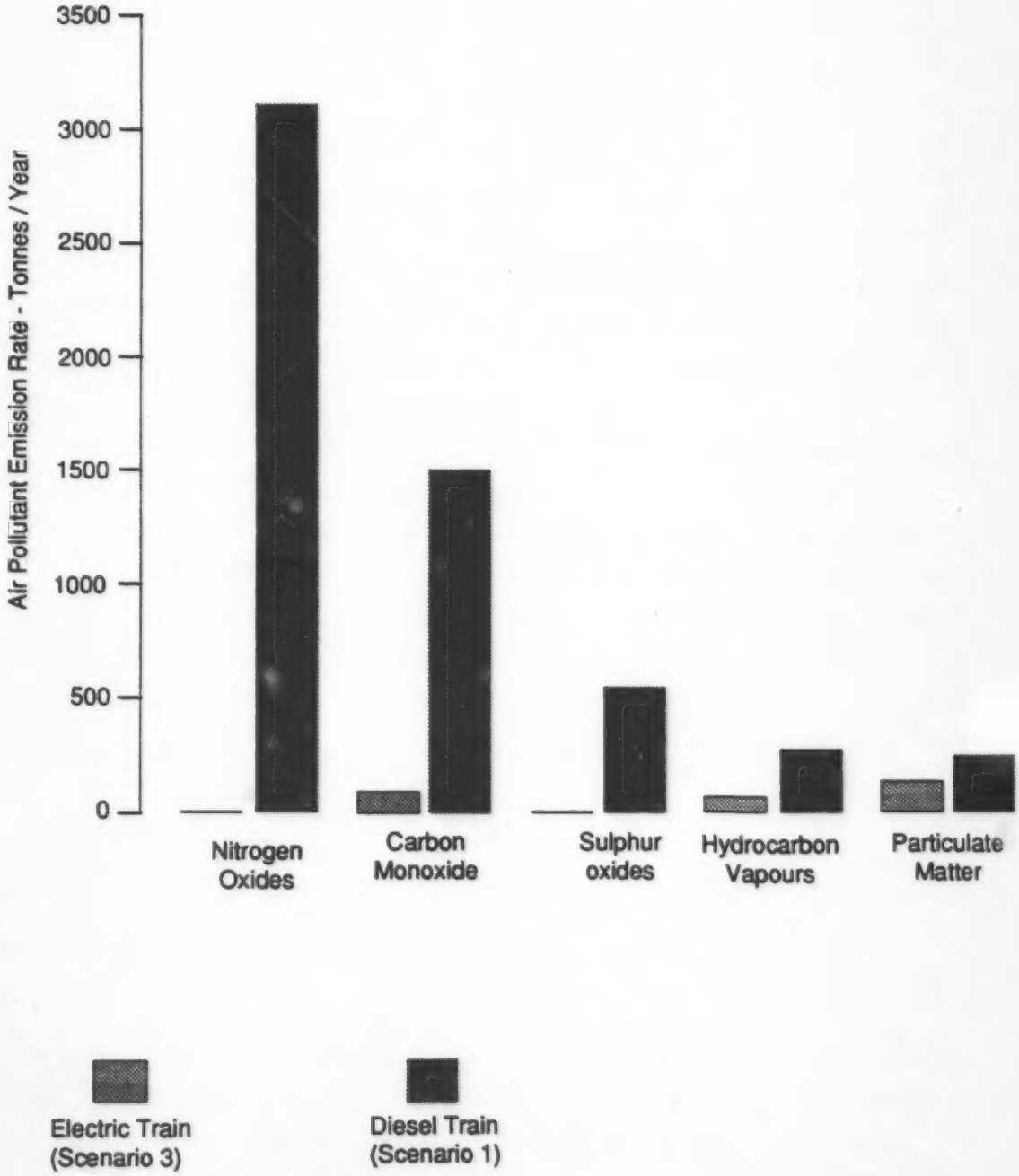
Water Resources and Fisheries

Spillage of liquid pollutants can occur from several sources in a passenger railway operation, most commonly as fuel spillage or as loss of cooling water. Both these forms of spillage would be significantly reduced with an electrified railway system due to the elimination of fuelling requirements and some cleaning and maintenance operations which are required specifically for diesel locomotives.

Geological Systems/Vegetation/Wildlife

It is expected that the operation of the electrified GO Rail System will have little or no effect on geological conditions, vegetation and terrestrial wildlife.

Figure 7.1
COMPARATIVE AIR POLLUTION EMISSIONS



7.2.3.2 Social Environment

Community Effects

The operation of the electrified GO system will result in little or no change to impacts on community systems when compared to present diesel operation. Property values adjacent to the rail corridors may be aversely affected by the aesthetic effects of the catenary (as described later in this section) but may benefit from the reduced levels of noise and air pollution.

Economic Considerations

Given that maintenance requirements for electric locomotives (see Section 6.6) are less (in terms of costs) than those for diesel locomotives, it is expected that employment of maintenance staff at the repair facilities will decrease somewhat after electrification.

Electric locomotives demonstrate a higher availability when compared to diesel electric locomotives in the same service. The lower availability of the diesel units is due to their greater maintenance requirements and to the refuelling requirements.

Noise

This section of the report considers briefly, the effects on ambient noise which electrification of GO Transit's rail service will have. The noise impact of GO electrification is examined both in terms of the change in sound level of the GO trains operating alone, and in terms of the change in the overall railway sound levels, with all rail traffic considered.

Noise generated by transformers installed along the electrified rail corridors is also briefly considered.

If the GO Transit operation is considered in isolation, the use of electric in lieu of diesel locomotives is expected to result in a five to ten decibel noise reduction. The actual sound level reduction would depend on such factors as the type of rail (continuous welded or not welded), the average number of locomotives per train, the

average number of cars per train, and the average train speed. A summary of several cases studied is provided in Table 7.2.

The equivalent sound levels reported in Table 7.2 are energy averaged sound levels which take into account: 1) the maximum passby sound level; 2) the duration of the passby; and, 3) the number of passbys in a specified time period. Equivalent sound levels are used by the Ministry of the Environment to assess the noise impact of trains in the context of land use planning.

The maximum passby sound levels at 15 m from the track centreline for ten car diesel and electric trains travelling at 80 km/hr, are 97 dBA and 82 dBA respectively. The drop in maximum passby sound level that would follow electrification is not considered to be as representative of community reaction to noise as the change in equivalent sound level, because the maximum passby sound level does not take into account as many factors.

If only the GO Transit rail system is considered, electrification would result in noise reduction at most residences impacted by rail traffic of five to ten decibels, as shown in Table 7.2. These significant noise reductions attributable to GO electrification, cannot be considered in isolation as GO Transit shares rail corridors with other trains that may not be converted to electric power.

TABLE 7.2

Sound Levels for Diesel and Electric Trains

RAIL TYPE	TRAIN SIZE		SPEED [km/h]	DIESEL* [dBA]	ELECTRIC* [dBA]	CHANGE IN SOUND LEVEL [dB]
	LOCOMOTIVES	CARS				
Not Welded	1	6	80	64	57	-7
	1	8	80	65	58	-7
	1	10	60	63	57	-6
	1	10	80	65	59	-6
	1	10	100	66	61	-5
	2	10	80	67	60	-7
Continuous Welded	1	6	80	64	55	-9
	1	8	80	64	56	-8
	1	10	60	63	55	-8
	1	10	80	64	56	-8
	1	10	100	66	58	-8
	2	10	80	67	57	-10

*One hour equivalent sound levels based on one train per hour predicted using Stamson 4.1. Receiver distance is 15 m over absorptive ground. Receiver height is 1.5 m.

To illustrate the effects of electrification on overall rail corridor noise, the Lakeshore West GO line is considered. The change in overall rail sound levels is expected to be two decibels or less, as indicated in Table 7.3. This table shows the predicted equivalent sound levels for the day and night time periods used by the Ministry of the Environment to assess noise impact in land use planning. Table 7.4 gives the basis for the predicted sound levels in Table 7.3.

TABLE 7.3

Noise Impact of GO Electrification - Lakeshore West GO Line

TIME PERIOD	SOUND LEVEL WITH DIESEL GO TRAINS* [dBA]	SOUND LEVEL WITH ELECTRIC GO TRAINS* [dBA]	CHANGE IN SOUND LEVEL [dB]
Day (7:00 - 23:00)	73	71	- 2
Night (23:00 - 7:00)	73	73	0

*Equivalent sound levels predicted using Stamson 4.1. Receiver distance is 15 m over absorptive ground. Receiver height is 1.5 m.

TABLE 7.4

Train Types and Numbers - Lakeshore West GO line

DESCRIPTION OF TRAIN	FREIGHT	YARD	VIA	GO
Number of Trains				
Day (7:00 - 23:00)	12	10	23	49
Night (23:00 - 7:00)	12	4	1	6
Number of Cars/Train	100	15 / 60 day / night	4	10
Number of Locomotives/Train	3	1 / 2 day / night	1	1
Speed [km/h]	45	45	70	80

If rail traffic (other than GO trains) is assumed to increase at a rate of 2.5% per year for a period of ten years, the equivalent sound levels in Table 7.3 would be approximately one decibel higher but, the predicted change in sound level following GO electrification would remain essentially the same.

Table 7.3 indicates that although the sound levels produced by the GO trains would be reduced following electrification, the reduction in total rail noise would be less significant on busy rail corridors where GO trains make up only a portion of the rail traffic.

Table 7.4 presents the Lakeshore West GO line as one of the more heavily used lines in terms of GO train traffic as a percentage of all rail traffic. As a result, in most places the predicted noise impact of GO electrification will be 2 decibels or less as indicated in Table 7.3 due to the mix and frequency of traffic outlined in Table 7.4.

At locations where the GO train traffic is predominant, electrification is expected to result in a five to ten decibel reduction in rail sound levels as indicated in Table 7.2. If other rail services such as freight and VIA also convert to electric locomotives, the expected reduction in sound levels would again be five to ten decibels.

To power the electric locomotives, transformers will have to be installed throughout the GO Transit rail system. These transformers, which are expected to range in size from 10 MVA to 50 MVA, could be considered a noise concern due to transformer hum. However, with adequately designed enclosures, the noise impacts can be mitigated.

The major noise sources in a passenger rail yard are idling diesel locomotives and vehicle movements. GO electrification will reduce the noise from both idling locomotives and vehicle movements. Consequently, although a reduction in sound levels from yards is expected following electrification, further study would be required to determine the specific reduction at each yard.

Visual Impacts

The presence of an elevated structure along a rail corridor could negatively influence the aesthetic quality of the area by conflicting with open space, by obstructing or detracting from views and could result in a decrease in the value of adjacent property.

A myriad of factors including cultural conditioning, visual associations and analytic experience affect human aesthetic response to form, space, balance order and harmony and influence how we determine if something is visually obtrusive.

Located about 7 metres above the rails, the OCS with its support poles every 70m could impart visual impact along certain sections of the rail corridors. This impact may be particularly evident where the rail track is built on an embankment, in open spaces and at railway level crossings. A few specific examples of sections where the catenary may visually intrude are:

- On the Lakeshore line alongside the Gardiner Expressway/High Park area east of the Humber River;
- Adjacent to the Royal Botanical Gardens in Hamilton where the railway embankment is visible from the gardens;
- Adjacent to residential developments where the catenary would be visible above the existing sound barrier;
- At some railway overpasses and level crossings;
- At yards and stations (eg. Union), where a multiplicity of catenary wires is required to service all electrified tracks.

Visual impact can be reduced by minimizing the structural dimensions of the catenary and its support masts and by maximizing the distance between supports.

Further study and public input would be required to assess the visual effects of the catenary system and to determine the requirements for the least intrusive system configurations in critical sections.

Safety

The high voltage in the overhead electrification system presents some safety risks to both railway maintenance personnel and members of the public. Fatalities have been occurred where trespassers on railway property have come in contact with the overhead catenary.

In addition, the overhead wire catenaries at the level railway crossings on the GO Transit rail system could be susceptible to accidental damage and to acts of vandalism.

Direct automobile impact with the support structure could be practically precluded if support poles are placed sufficiently distant from the roadway. Where vehicle impact is possible, poles would have to be mechanically protected.

Considering the above safety concerns and in light of recent acts of vandalism on power transmission towers, certain measures may be required to protect the general public. These measures could include tight controls on access to railroad corridors and the provision of tamper proof and "climb proof" support poles.

In the event that additional road rail grade separations are introduced to eliminate collision risk, enhanced electrification safety can be counted as a secondary benefit.

At overhead bridge crossings of the railway, where the catenary is connected to the structure, the accessibility of the catenary from above and hence its security must be investigated. It will be necessary to install measures to prevent people on the overhead bridge from reaching the catenary below.

The consequence of a rail derailment bringing down the catenary should be investigated both from the public safety and from the operational points of view.

Electromagnetic Fields - Health Concerns

Recently concerns have been raised about the health effects of the electromagnetic fields near power transmission lines. Consequently, the overhead catenary required for GO electrification may be viewed as a health concern by both commuters and residents living near the GO lines.

The strength of the greatest electromagnetic field that would be experienced by commuters are estimated to be on the order of 10 μT (microtesla).

As a guide to control the health hazards of physical agents like electromagnetic fields, The American Conference of Government Industrial Hygienists (A.C.G.I.H.) have developed threshold limit values (TLVs). These values are used in the workplace and are based on an time-weighted exposure for a normal eight hour work day. The TLV for magnetic field density at 60 Hz (power line frequency) is B_{TLV} = 1000 μT. The TLV for pacemaker wearers (at 60 Hz) would be a factor of ten lower or 100 μT.

Thus, the greatest field density that would be experienced by commuters is 1/100 that of the threshold limit values and 1/10 that of the TLV expected to be safe for a user of a cardiac pacemaker.

Electromagnetic Interference

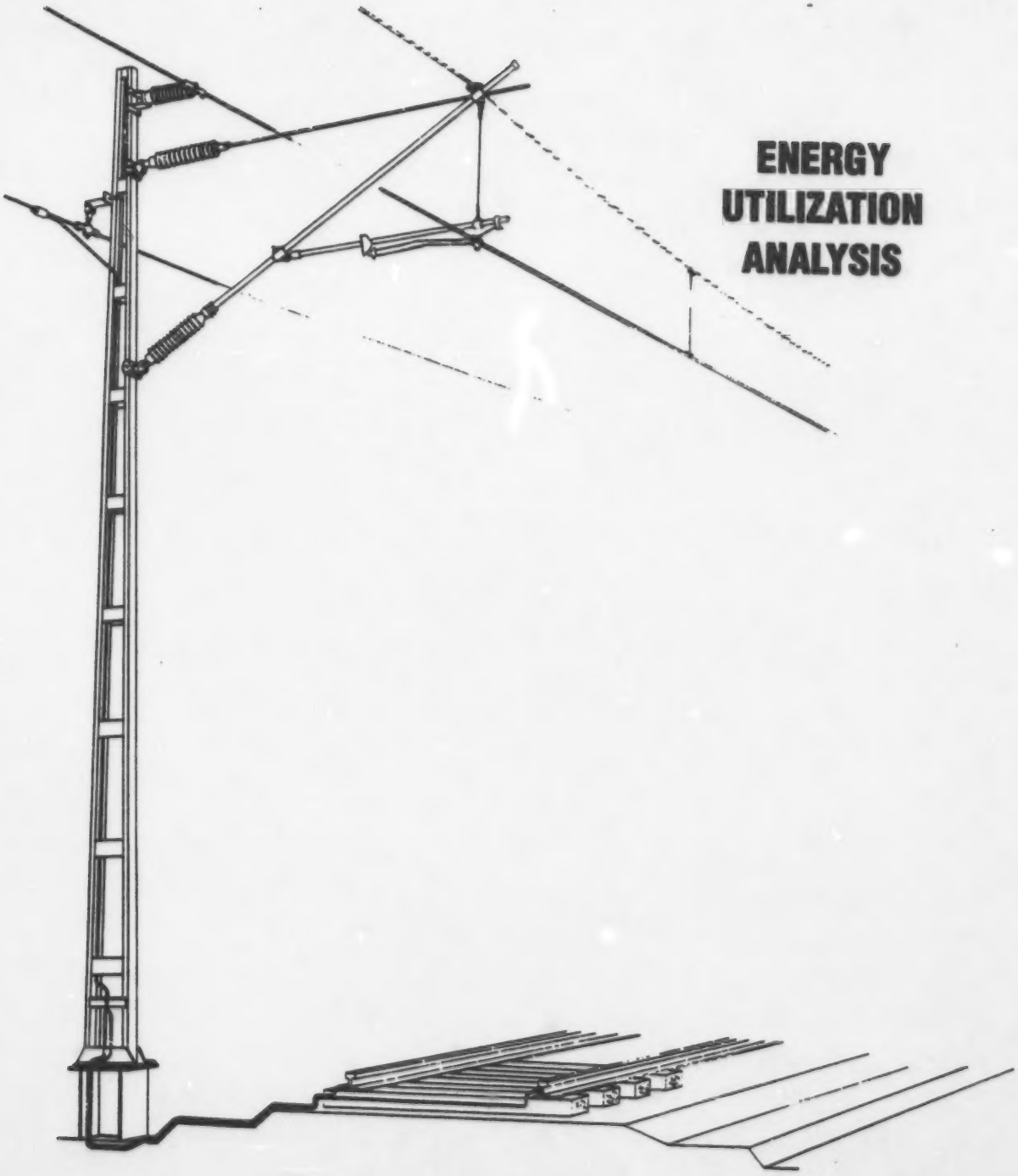
Electromagnetic interference (EMI) is the magnetic coupling between electrical circuits. This coupling of energy from one circuit to another can cause misoperation of low energy (electronic) circuits if precautions are not taken.

Locomotive builders have now achieved success in integrating power, electronic and microprocessor systems.

Fibre optics, in place of wayside cabling will also be employed. These steps will go a long way toward immunizing the rail corridors from electromagnetic interference problems created by its own 25 kV OCS as well as other transmission lines.

8.

ENERGY UTILIZATION ANALYSIS



CPCS Ltd. in association with Hatch Associates Ltd.

8. ENERGY UTILIZATION ANALYSIS

This section discusses the train performance calculations (TPC's) for the various options presented in Section 2.1. The objective of the TPC's was:

- to determine electric power, electric energy and diesel fuel requirements for each scenario;
- to examine train travel (journey) times under each option and to examine how locomotive type affects the train schedules;
- to provide the basic power profiles along the line for the selection of the appropriate overhead contact system (OCS) for the electrification options.

8.1 TPC MODEL

The TPC used for the studies is a multi-train model for the simultaneous simulation of scheduled train movements along single or double track lines (VOLTRAN). The model performs, in addition to the conventional TPC modelling of each train on the line, all necessary analysis to determine daily maximum demand and energy requirements for electrified railways and catenary voltage profile calculations for electrification studies. It is believed that this is the only model of this capability available in North America at the present time.

8.2 OPTIONS SIMULATED

The time available for this study did not allow the complete simulation of all the lines operated by GO Transit. It was decided therefore, to study in detail the Lakeshore line from Oshawa to Hamilton, representing a major portion of the passenger volume on the GO Transit lines, and the line from Richmond Hill to Union Station. For these two lines the three options studied were:

- Diesel traction using the GM, F59PH 3000 HP diesel locomotive;
- Electric traction using the ABB, ALP44 4500 kW locomotive and

- Electric traction using EMU's with motorized units similar to the ABB X10 paired units.

8.3 ASSUMPTIONS FOR SIMULATIONS

8.3.1 Train Consists

For the diesel option a ten bi-level car consist hauled by the F59PH locomotive was assumed.

For the 'electric' option a ten bi-level train hauled by a locomotive equivalent to the locomotive supplied by ABB to the New Jersey system, designated ALP44 was assumed which was found to be the most suitable amongst recent electric locomotive types for the GO Transit system.

For the EMU option the ABB X10 type two-unit EMU was assumed. The weight of this unit, which for European application is 2-50t cars, was modified to fit North American requirements. The motorized unit was assumed to weigh 95t, while the second unit was assumed to be the regular bi-level car weighing 70t.

For information purposes a 12-car train was simulated under diesel and electric locomotive consists (see Table 8.1) but these results have not been carried forward for further analysis.

8.3.2 Locomotive Characteristics

The tractive effort (TE) and other relevant performance characteristics of the F59PH, 3000 HP GM diesel locomotive were made available by GO Transit for the study.

The TE curve of the ABB, ALP44, 4500 kW electric locomotive was obtained from the ABB Traction Division in Sweden.

The TE curve for the above modified ABB X10 type EMU was calculated from the characteristics of the four dc driving motors specified in the ABB brochure for the X10 unit and from the typical acceleration figures specified by ABB for the standard units.

For both the ABB locomotive and the EMU a conservative approach was taken, inasmuch the capability as calculated from the ABB data was reduced by about 15% in the actual TPC input. No such reduction was used for the GM F59PH locomotives, for which the performance characteristic is assumed to be guaranteed.

To illustrate the relative performance of the motive power types the TE for the diesel, electric and EMU options was plotted on the same graph in Figure 8.1. For the X10 EMU, the TE curve represents that of five units equivalent from an application point of view to one locomotive in the other options.

The electric locomotives have clearly a superior performance. Care should be taken, however, in comparing the three TE curves. The ALP44 locomotive has a nominal rating of 4500 kW (approx. 7000 HP), twice that of the F59PH. Even if the power ratings are properly discounted and the comparison is made based on a power/weight ratio, the electric traction has a better performance. This is partly due to the possibility of the overload utilization relative to the gains achievable with the gearing optimal for mass transit service.

8.3.3 Train Resistance

The train resistance formula, a modified Davis formula, used in the TPC is given in Appendix B. The Davis formula was evaluated up to the term of the square of speed, which is quite satisfactory for the purposes of this study. The higher terms come into play only for sustained high speed operation above 150 km/h.

The coefficients in the formula used were checked against the TPC's done by General Motors for both the Lakeshore line runs and the 10 car train acceleration run. The comparison of the CPCS and GM acceleration curves which are in very good agreement is shown in Appendix C.

The acceleration achievable with 10 car trains is considerably below the comfort limit of about 0.9 m/s^2. The average acceleration with diesels, limited by the TE curve is about 0.3, while the acceleration as limited by the ALP44 is about 0.5. The acceleration achievable with the X10 EMU's is about 0.65. The maximum acceleration for the European model of the EMU's with 50t cars is 0.8.

8.4 DESCRIPTION OF TPC FORMULATIONS

Based on the discussions in Sections 2 and 4, and the time limitations of the study, it was decided to perform 'snapshot' TPC's for the following scenarios:

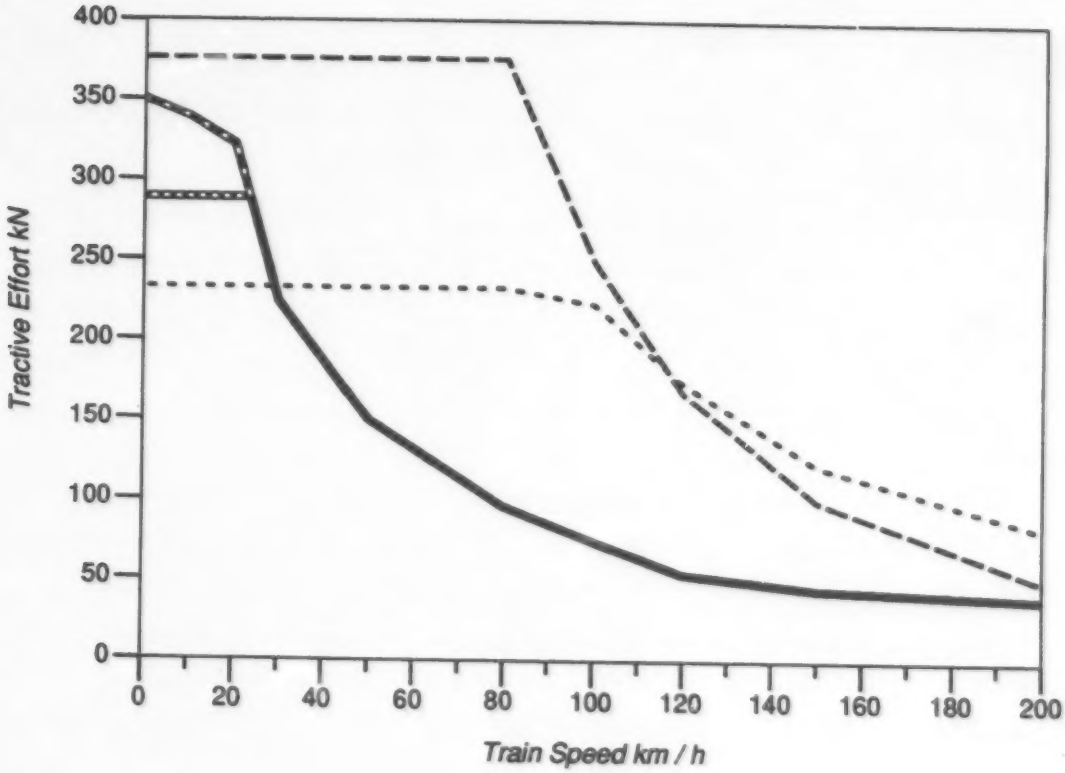
- Lakeshore Line

  Trains with 10 bi-level cars of 70t/car, on the Oshawa-Union Station-Hamilton line, total distance of 114.1 km; 18 stations including Union Station excluding terminals. Train frequency 10 minutes during the designated peak hours of 6:30 AM to 9:00 AM and 15:30 PM and 19:00 PM; train frequency 30 minutes in the remaining off peak time, except for the period between 2:00 AM and 5:00 AM when there is no train service. The dwell time is 60 seconds at each of the 18 stations designated.

- Richmond Hill Line

  Trains with 10 bi-level cars of 70t/car on the Richmond Hill-Union Station line, total distance 33.8 km; 3 stations excluding terminal. Train frequency 20 minutes during the designated peak hours of 6:30 AM to 9:00 AM and 15:30 PM and 19:00 PM; train frequency 60 minutes in the remaining off peak time, except for the period between 2:00 AM and 5:00 AM when there is no train service. The dwell time is 60 seconds at each of the 3 stations designated.

Figure 8.1
TRACTIVE EFFORT CHARACTERISTICS
Locomotive and EMU



F 59 PH Diesel - 118 tonne (Assuming 30% available adhesion)
(Assuming 25% available adhesion)

ALP44 Electric - 92.5 tonne (Operating at 25% available adhesion)

5 - X 10 EMU's

Note: For additional data see Appendix A

A complete 24 hour traffic simulation was performed for both lines and for both diesel and electric traction and for the EMU's. These simulations were used to determine daily energy consumptions, to give a basis for rolling stock requirement analysis, and to provide for the electric option, data for power supply and OCS voltage profile calculations.

In addition, single TPC's were run for all options to examine the effect of inserting additional stations on the Richmond Hill Line and for a 12 car train option.

8.5 RESULTS OF SIMULATIONS

The results of the TPC runs are presented in terms of journey times, and round trip energy consumptions obtained from single TPC's, daily train travel diagrams and power demand profiles obtained from 24 hour simulations.

8.5.1 Single Run TPC's

To obtain an overall appreciation of the relative merits of the various options studied, and to assist in the economic evaluations of the lines not simulated, Tables 8.1 and 8.2 were prepared. These tables present single train run simulations for the Lakeshore Line and the Richmond Hill Line for the three principle traction options, diesel, electric and EMU. In addition to the basic 10 car train option, single TPC runs were also made for a 12 car train.

For the Richmond Hill lines two conditions were simulated. One without any track speed restriction (Table 8.2A), and one with the existing speed restrictions (Table 8.2B).

Table 8.3 illustrates the effect of adding three new stations on the Richmond Hill line. This case was only run without the speed restrictions. The stations were inserted between Union Station and Oriole, equally spaced, as the exact locations are not defined.

Tables 8.1, 8.2 show, in addition to the basic options, three alternatives. These locomotive alternatives are presented to illustrate the difference between electric and diesel traction and to examine benefits from higher locomotive power rating. The 2208 kW or 3000 HP electric locomotive is the diesel equivalent but still using the prorated TE curve of the ALP44. The 6000 kW electric locomotive is simply the prorated version of the 4500 kW ALP44. The two F59PH diesels demonstrate the comparison between the F59PH and the ALP44 based on equal power rating.

TABLE 8.1

GO Transit
Lakeshore Line Oshawa-Hamilton

Train Transit Times
and Round Trip Energy Consumption

Locomotive Type	Trailing Tonnes	Hamilton-Oshawa Minutes	Oshawa-Hamilton Minutes	Energy kWh/ Litres
F59PH 3000HP diesel	700	122	124	6804/ 1905
ABB ALP44 4500kW electric	700	99.5	101.5	10100
X10 EMU 5-units electric	825*	91.5	93	11250
2208 kW (3000 HP) electric	700	116.5	118	7175
6000 kW electric	700	97.5	99.5	11095
2-F59PH 3000HP diesels	700	102	103.5	10300/ 2885
1-F59PH 3000HP 12 cars (+)	840	129	132	7392/ 2070
ABB ALP44 4500kW 12 cars (+)	840	106	107	11018

* Gross tonnes
\+ All trains 10 cars except as noted

TABLE 8.2A

GO Transit
Richmond Hill Line

Train Transit Times
and Round Trip Energy Consumption
No Speed Restrictions

Locomotive Type	Trailing Tonnes	Union Station Richmond Hill Minutes	Richmond Hill Union Station Minutes	Energy kWh/ Litres
F59PH 3000HP diesel	700	32.5	26.5	1678/ 470
ABB ALP44 4500kW electric	700	25.0	23.0	2226
X10 EMU 5-units electric	825*	23.0	21.5	2336
2208 kW (3000 HP) electric	700	31.5	25.0	1770
6000 kW electric	700	24.5	22.5	2455
2-F59PH 3000HP diesels	700	24.5	22.5	2400/ 672
1-F59PH 3000HP 12 cars (+)	840	35.0	27.5	1825/ 511
ABB ALP44 4500kW 12 cars (+)	840	26.5	24.0	2524

* Gross tonnes
\+ All trains 10 cars except as noted

TABLE 8.2B

GO Transit
Richmond Hill Line

Train Transit Times
and Round Trip Energy Consumption
with Current Speed Restrictions

Locomotive Type	Trailing Tonnes	Union Station Richmond Hill Minutes	Richmond Hill Union Station Minutes	Energy kWh/ Litre
F59PH 3000HP diesel	700	42	37.5	1455/ 407
ABB ALP44 4500kW electric	700	39	36	1660
X10 EMU 5-units electric	825*	38	35.5	1680
2208 kW (3000 HP) electric	700	41	36.5	1450
6000 kW electric	700	39	36	1730
2-F59PH 3000HP diesels	700	39.5	36	1857/ 520
1-F59PH 3000HP 12 cars (+)	840	45.5	38.5	1628/ 456
ABB ALP44 4500kW 12 cars (+)	840	40.5	37.5	1915

* Gross tonnes
\+ All trains 10 cars except as noted

TABLE 8.3

GO Transit
Richmond Hill Line

Effect of Three New Stations on
Train Transit Times
No Speed Restrictions

Locomotive Type	Trailing Tonnes	Union Station Richmond Hill Minutes	Richmond Hill Union Station Minutes	Energy kWh/ Litres
F59PH 3000HP diesel no new stations	700	37	29.5	1695/ 475
F59PH 3000HP diesel three new stations	700	48	37.5	2107/ 590
ABB ALP44 4500kW electric no new stations	700	30.5	27.5	2190
ABB ALP44 4500kW electric three new stations	700	38.5	33	2625
X10 EMU 5-units electric no new stations	825*	31	26.5	2460
X10 EMU 5 units electric three new stations	825*	35.0	31.5	2785

* Gross tonnes

8.5.2 Daily Traffic Simulation

The principal objective of the 24 hour traffic simulation was:

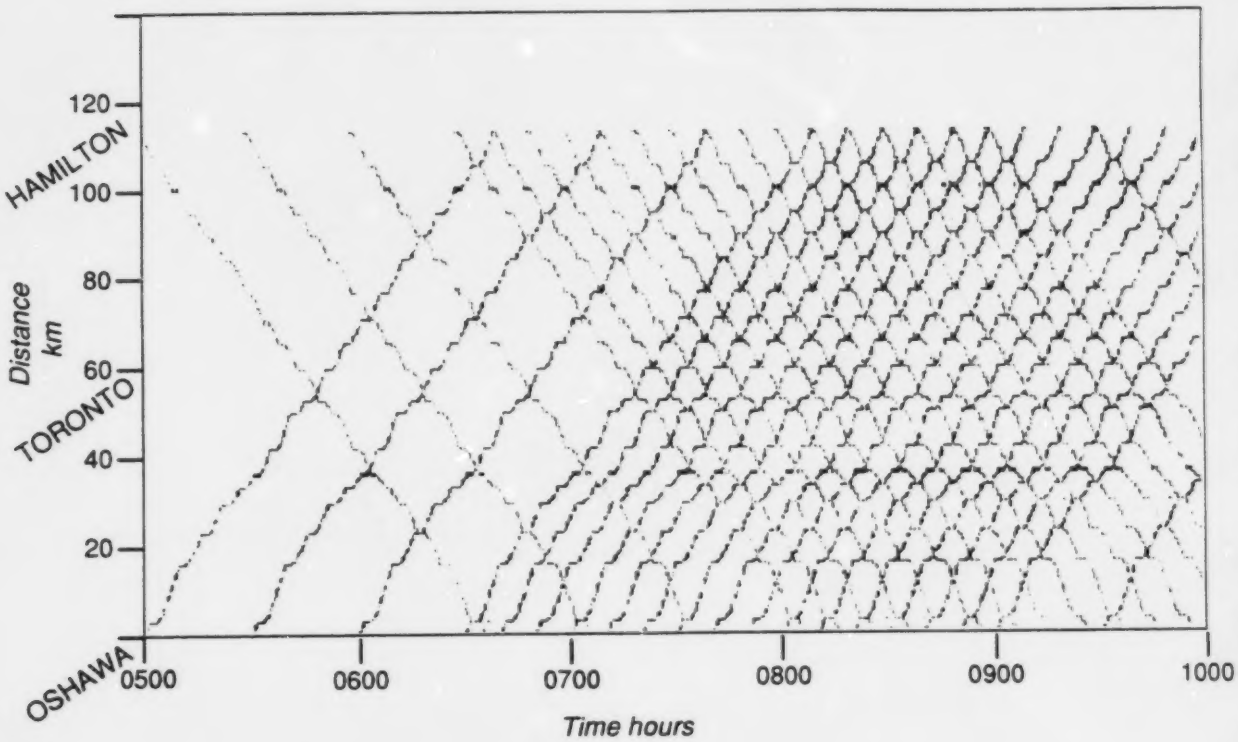
- to find out if there is a limitation in satisfying the projected train schedules(e.g. headway);
- to determine coincident pantograph power profiles for the study of the electrification options;
- and to assist in determining rolling stock requirement from the train travel diagrams.

A typical example for a train travel diagram for the Lakeshore line is shown in Figure 8.2. It is for the ALP44 option. Only the period between 5:00 AM and 10:00 AM is shown for clarity. Travel diagrams for the Richmond Hill line and the diesel options are shown in Appendix D-4.

8.5.3 Power Demand Simulation

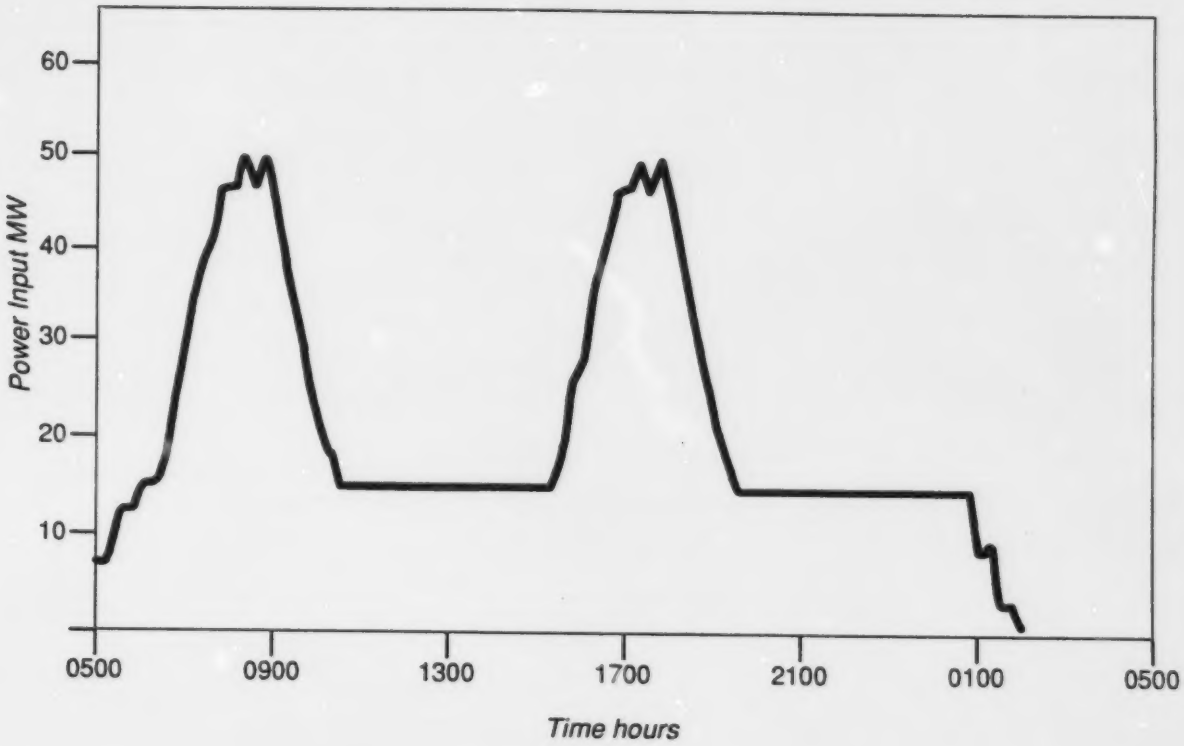
Figure 8.3 shows the daily load curve on the electrified Lakeshore Line, based on the ALP44 electric locomotive and 700 t trailing load. The instantaneous locomotive power demands are integrated over 15 minutes to give the demand curve as seen by the utility demand metering. The actual peak loads are somewhat higher than the 15 minute averages. The one minute integrated demand is shown in Appendix D-2. This is the demand curve which was used for the voltage profile calculations. Figure 8.4 shows the 15 minute demand curve for the Richmond Hill line. The one minute demand curve is shown in Appendix D-5. Appendix D-3 also presents the 15 min. integrated demand curves for the EMU option on the Lakeshore line. Only these two lines were simulated in detail. Demand estimates for the other GO Transit lines were based on the extrapolation of these results.

Figure 8.2
TRAIN TRAVEL DIAGRAM FROM 5 AM TO 10 AM
Lakeshore Line Oshawa-Hamilton



1 - ABB ALP44 4500 kW electric loco - 10 cars 700 t trailing

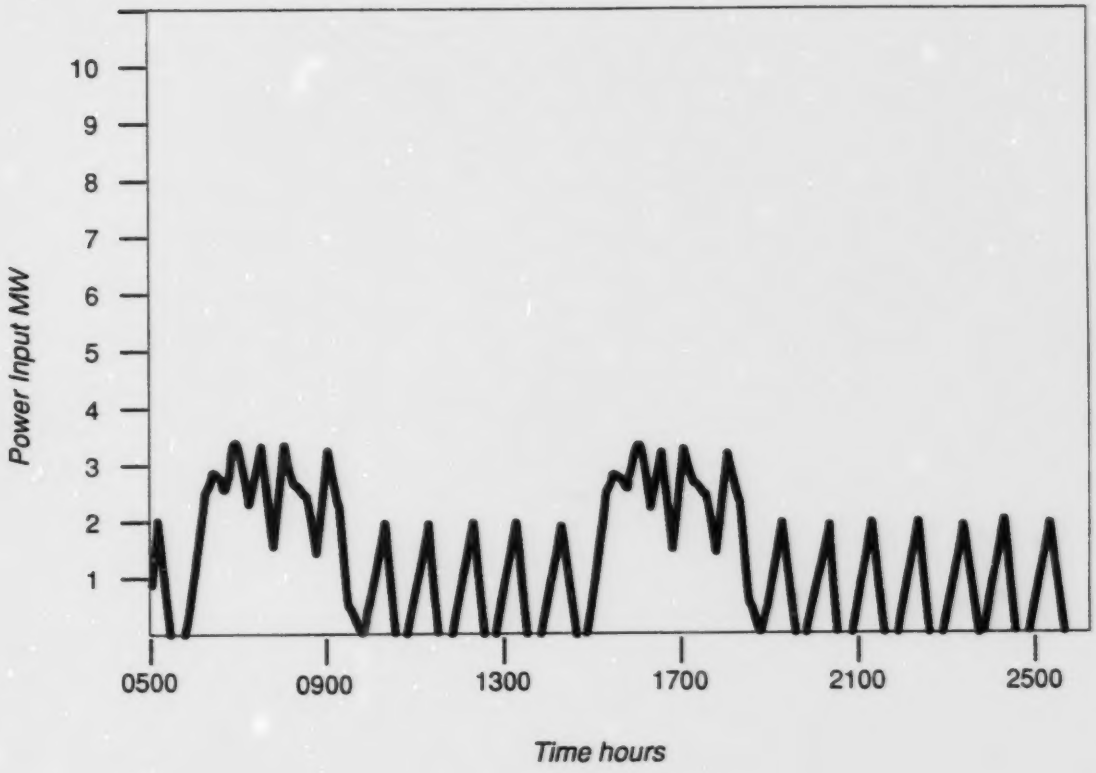
Figure 8.3
DAILY LOAD CURVE
Lakeshore Line Oshawa-Hamilton
Off-Peak 30 min. / Peak 10 min.



1 - ABB ALP44 4500 kW electric loco - 10 - 70 t cars trailing

Total energy over km 0 to 114.1	= 617.6 MWh
Average power	= 25.7 MW
Peak power	= 48.7 MW
Load factor	= 52.8 %

Figure 8.4
DAILY LOAD CURVE
Richmond Hill Line
Off-Peak 60 min. / Peak 20 min.



1 - ABB ALP44 4500 kW electric loco - 10 - 70 t cars trailing

Total energy over km 0 to 33.8	=	57.3MWh
Average power	=	2.4 MW
Peak power 15 min. avg.	=	3.4 MW
Load factor	=	70.31 %

8.6 DISCUSSION OF RESULTS

8.6.1 Journey Times

Table 8.1 shows that substantial reduction in journey times can be achieved on the Lakeshore Line, if electric traction is used with locomotives equivalent to the ALP44, 4500 kW electric locomotive. The reduction is about 20% or about 22 minutes in either direction. With ABB X10 type or equivalent EMU's, a further eight minute reduction would be possible, or a total reduction of about 30 minutes compared with diesels. This improvement is due to the higher HP rating of the electric locomotives and the more favourable TE curve relative to their HP rating, particularly for EMU's.

Table 8.2A shows that if speed restrictions could be removed from the Richmond Line, a similar gain in journey times could be obtained. From Union Station to Richmond Hill, with the line going upgrade, the relative improvement is in excess of 20% or approximately 7 minutes.

Table 8.2B shows that with the current speed restrictions on the Richmond Hill line the higher rating of electric locomotives or EMU's cannot be fully utilized. The journey time is reduced by only 3 to 4 minutes.

Table 8.3 illustrates that adding three new stations on the Richmond Hill line the journey time increases by 11 minutes for diesel and 8 minutes for electric traction. With electric traction, however, the total journey time is still only about one minute longer than the journey time with diesels and without the new stations.

The seemingly large loss in journey time for adding new stations can be explained by examining the GM 700t train acceleration curve with the F59PH locomotive. 96 km/h speed is reached in roughly 3.5 minutes and 3.5 km. At this speed, 3.5 km can be covered in about 2.2 minutes. The loss in time for adding one acceleration period is therefore 1.3 minutes. About 1.0 minute is lost in deceleration, making a total loss including dwell time about 3.3 minutes per station.

The price to pay for reduction in journey times is increased energy consumption. This is due increased power at higher speeds and increased energy input during the acceleration cycles to attain higher speed.

8.6.2 Power Demand and Energy Consumption

Figure 8.3 illustrates a simulated daily load curve on the Lakeshore Line. The 15 minute maximum demand is 46.9 MW at a daily load factor of 57.6%, which is relatively high. The daily energy consumption is 618 MWh, or about 173,000 litre diesel fuel equivalent.

The Lakeshore line demand was separated for the East and West sections to examine the impact of supplying these sections from different Ontario Hydro substations. The daily 15 minute maximum demand is 26.3 MW and 25.7 MW for the east and west sections respectively, with daily load factors still above 50%.

Figure 8.4 shows the daily load curve for the Richmond Hill line. The 15 min. integrated peak demand is 3.4 MW and the daily load factor is 70%. The reason for this unusually high load factor is that the demand integration time is long relative to the length of the line.

8.6.3 Limits to Diesel Operation

Unless there is an unexpectedly high increase in passenger volume in the next ten years, no technical limit can be foreseen for diesel operation. The train frequency assumed in this study for the Lakeshore line was 10 minutes during the peak. This could be reduced to 5 to 6 minutes using the F59PH locomotive and 10 car trains, without running into major signalling problems. The limits to diesel operation relate to economics, journey times and quality of service.

8.6.4 Impact of Electricity Tariffs on Train Scheduling

The cost of electricity is derived from a two part tariff (Appendix E), for "Demand" and "Energy".

"Demand" is established monthly as a fifteen minute average of the maximum energy flow rate (kilowatts) drawn by the system (or each substation depending on agreed metering contract). It will always occur during peak train service and directly reflect the intensity of service.

"Energy" is a continuous aggregation of all energy consumed by the railway (kilowatt-hours) during a monthly billing period.

In the GO Transit context simulated in this study, the monthly cost of demand is roughly equal to the monthly cost of energy consumed. This means that the incremental cost of train energy off-peak, which does not affect the demand charge, is roughly one-half the system average cost. Thus an extra train operated off-peak draws energy at nominally half price.

If the off-peak train is reduced to a two-car EMU in lieu of a ten car loco set, energy falls to one-fifth the loco set. In effect off-peak two-car EMU service could be introduced and run at one-tenth the basic system train energy cost.

8.7 SUMMARY AND CONCLUSIONS FROM RESULTS

8.7.1 Summary of Results

A series of single TPC runs and daily traffic simulations were carried out for the three basic options of diesel traction using the F59PH 3000 HP locomotive, electric traction using a locomotive similar to the ABB ALP44 4500 kW locomotive, and electric traction using EMU's similar to the ABB X10 type pairs. The principal consist for each option was a 10 car 700t trailing load train, or the equivalent for the EMU's.

Table 8.4 gives a condensed summary of the results. The table is divided into results applicable to the Lakeshore line and results obtained for the Richmond Hill line, but used to extrapolate results for the other GO Transit lines.

The results shown for the Richmond Hill line are the average values of the line with and without speed restrictions.

TABLE 8.4

TRACTION OPTION	LAKESHORE LINE		RICHMOND HILL	
	Journey Time Min.	Energy kWh/ 1000GTkm	Journey Time Min.	Energy kWh/ 1000GTkm
Diesel F59PH 3000 HP	124	42	39.5	33
Electric ABB ALP44 4500 kW	101.5	63	34.8	40
Electric EMU X10 1140 kW/unit	93	70	33.5	44

Table 8.5 shows a rough energy cost comparison based on a diesel fuel cost of 25 cents/litre and an Ontario Hydro power rate of 6 cents/kWh, based on supply from the 115 kV system, a load factor of 50%, and 7.5% electrical losses in the OCS system. Using the .28 litre/kWh conversion assumed in the TPC's, the diesel fuel costs corresponds to 7 cents/kWh. A more detailed analysis of the energy costs is given in Section 13.

TABLE 8.5

TRACTION OPTION	LAKESHORE LINE		RICHMOND HILL	
	Journey Time Min.	Energy $/ 1000GTkm	Journey Time Min.	Energy $/ 1000GTkm
Diesel F59PH 3000 HP	124	2.9	39.5	2.3
Electric ABB ALP44 4500 kW	101.5	3.8	34.8	2.4
Electric EMU X10 1140 kW/unit	93	4.2	33.5	2.6

In contrast, it should be noted, that if the GO Transit lines were electrified and the same speed limits were used as obtainable with diesel traction, the energy costs would be reduced by about by about 18%.

8.7.2 Potential Fleet Size Reduction

On the Lakeshore line the time saving of electric locomotive headed trains is 22.5 minutes for a 124 minute diesel journey (Table 8.5). With a peak service interval of 20 minutes or less a reduced fleet size is clearly achieved even without rescheduling end point departures.

The worst case fleet is $\frac{121.5}{144}$ or 84% of diesel fleet

(assuming 20 minute layovers)

The best case fleet is $\frac{101.5}{124}$ or 82% of diesel fleet

(assuming re-scheduling fast turnarounds)

8.7.3 EMU in Off-Peak Service

The low energy cost of EMU operation providing off peak quality service (Section 8.6.4 refers) considered against the higher cost of EMU seats versus loco hauled seats (Section 6.5 refers) suggests that there would be an optimum mix of loco and EMU equipment for an electrified quality service GO Transit rail system.

The design of such a full quality service is outside the scope of this study but Scenario 4 as discussed in Section 13.1 has been created to investigate EMU economics.

8.8 OTHER ENERGY RELATED ISSUES

8.8.1 Use of Braking Energy - Regeneration

As noted in Sections 1.2.1 and 7.1 energy recovery and regeneration during braking has become a relatively simple feature of modern ac traction drives. Formerly only dc systems and specific European synchronous motor drives could claim useful regeneration.

In the early 1970's in the USA there was particular emphasis given to re-evaluation of energy storage devices either on-train or at trackside substations. Garratt Corporation fitted an EMU type train with a flywheel, specifically to recover and store braking energy. This demonstrated convincingly the significant amount of reusable energy available for re-starting the train. However the overall costs of such a flywheel system did not encourage further development.

Examination of TPC results indicate that braking energy (the dissipation of train kinetic energy) amounts to some 20 percent of traction energy consumed. For analysis it is assumed that 50 percent of braking energy can be returned to the OCS and it is further assumed that this will be taken up by other trains fed from the common substation. No special provision is contemplated at this time to reverse energy flow through the substations.

The theoretical energy saving is 50 percent of 20 percent or 10% of consumption. This case is examined in the financial analysis.

8.8.2 Installation of Peaking Plant Gas Turbine for Peak Shaving

The inherent nature of the electric traction load is usually low load factor (LF). However, the Lakeshore Line presents a fairly high LF.

The Hamilton - Oshawa power requirements are estimated at 47 MW peak and 27.4 MW average power for a daily LF of 57.6%.

Installing a 30 - 35 MW peaking gas turbine would further improve the LF to about 80%.

However, the cost of a typical 30 - 35 MW gas turbine installation complete with step-up transformer and switchgear, foundation, fuel storage and handling, would be approx. $25-30 million. The operating and maintenance cost could be around 6¢-7¢/kWh depending on the availability of gas or other fuel contracts. An economic analysis indicates that the power from the peaking plant would be more expensive than the power available from Ontario-Hydro.

Furthermore, the fuel burning peaking plant would have a negative environmental impact on the project. The other considerations are: location, operation and maintenance of a peaking plant by the transit authorities and reliability aspects of a single plant (i.e. any short forced outage may result in about $ 350,000/month penalty charge on the monthly demand charge!).

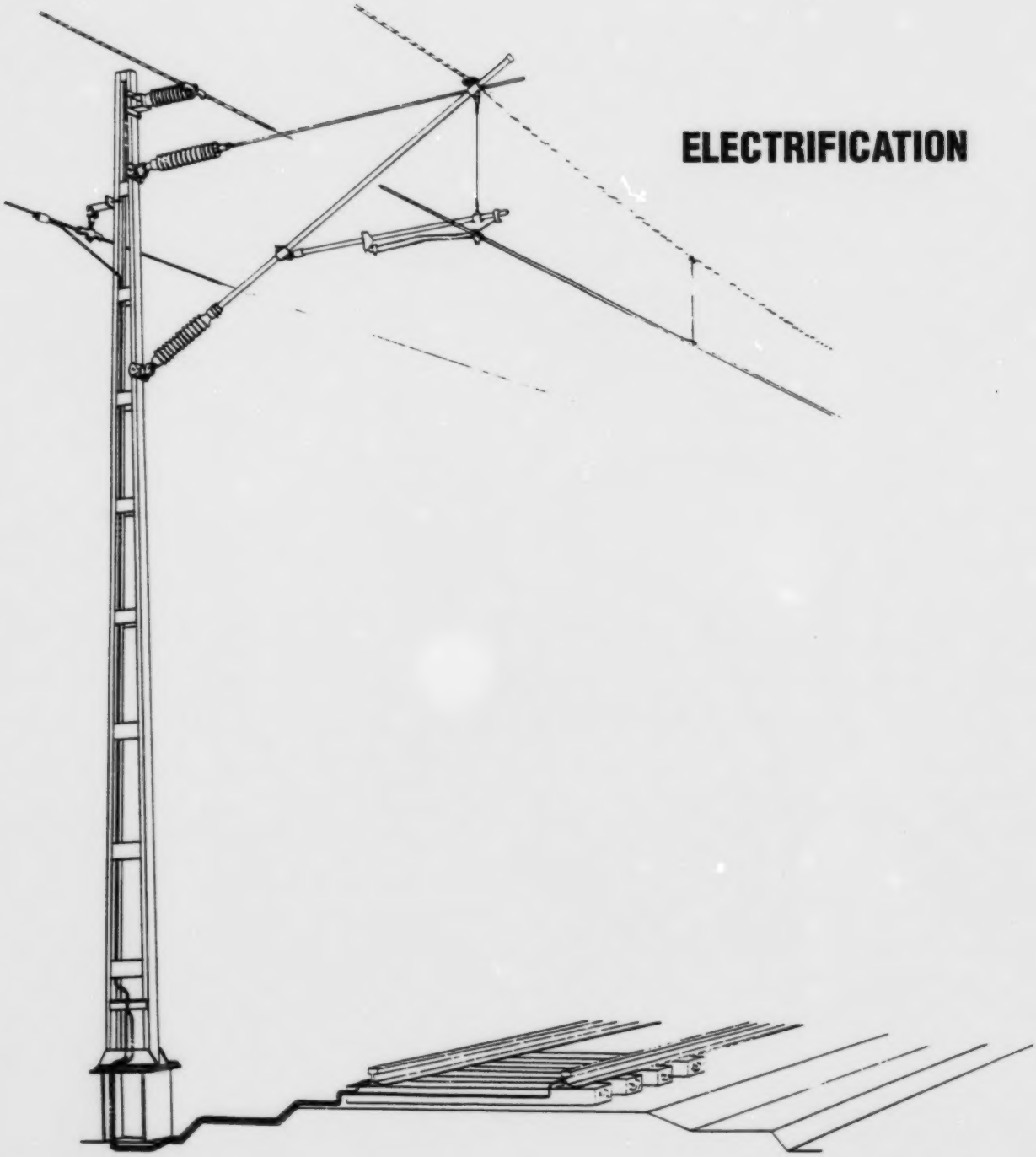
8.8.3 Cogeneration Plant

A cogeneration facility may be of interest only, if a third party could be found for taking delivery of the steam produced by the waste heat available.

A cogeneration plant would most likely be a base load facility, an unlikely application for GO Transit.

9.

ELECTRIFICATION



9. ELECTRIFICATION

9.1 REVIEW OF PREVIOUS STUDIES

Section 3 of the 1983 DelCan-Electrack study[1] provides an excellent overview of the electrification system options available, their technical characteristics and economic evaluation. To avoid repetition, only a brief summary will be given here for ease of reference.

9.1.1 600/750 V dc with Third (or Fourth) Rail

These systems are used typically for underground systems or could be used for systems as the previously planned GO-ALRT. The power supply would require a distribution network, usually owned by the railway company, with closely spaced feeder stations. This system is uneconomic for mass transit systems using heavy trains as planned currently by GO Transit.

9.1.2 1500 V dc with or without Third Rail

This system could be either overhead (OCS) type or employing a third rail. The system , while technically feasible, and used in open and underground metro systems, is uneconomic for heavy suburban mass transit, and lacks for such systems, advanced locomotive designs of the required capacities.

9.1.3 3000 V dc with Overhead Contact System

This system has been used extensively in many countries throughout the world in mainline electrification particularly before the second world war. Advancements in converter technology for electric locomotive application rendered the system uneconomic compared with 25 kV or higher voltage ac systems, particularly for high speed inter-city or suburban passenger train services.

9.1.4 25 kV ac System

This system has become increasingly popular for main line electrification and suburban mass transit systems in the last twenty five years and has become the most widely used system in the world for general purpose main line electrification. It has the greatest flexibility amongst the potentially viable systems for main line and suburban passenger line electrification with virtually no disadvantages compared with 3000 V dc.

9.1.5 Conclusion From Previous Studies

The DelCan-Electrack study provided a comparison between dc and 25 kV ac supply. For comparison purposes, 1500 V dc was chosen based on the findings that 3000 V dc motors cannot be accommodated in the EMU equipment then being considered. The study concluded that the optimum choice would be 25 kV ac based on minimum cost and considerations relating to potentially serious corrosion problems with direct current systems.

9.2 25 kV AND 50 kV SYSTEMS

Two versions of the 25 kV system are used. In both types, the voltage from the OCS to ground is 25 kV. The simple 25 kV system which was first used and is still widely used, is a 'single phase' 25 kV supply to the OCS, with the other side of the supply grounded and tied to the rails. The conceptual arrangement of such a system is shown in Figure 9-1.

In the +/- or two pole 25 kV system, the supply is 50 kV single phase, which is normally ungrounded at the source. At approximately 10 km intervals, a 50/25 kV autotransformer is installed with its centre point grounded and tied to the rails as shown in the sketch in Figure 9-2. The potential of either of the two poles is 25 kV to rail as it is in the single pole system. One of the poles is used as the contact system, the other serves as the feeder wire. The current drawn by the locomotive pantograph passes through the rails and back into the supply system through the centre tap on the autotransformer. On the high side of the autotransformer the current circulates in

Figure 9.1
SINGLE POLE 25 kV SUPPLY
CONCEPTUAL ARRANGEMENT

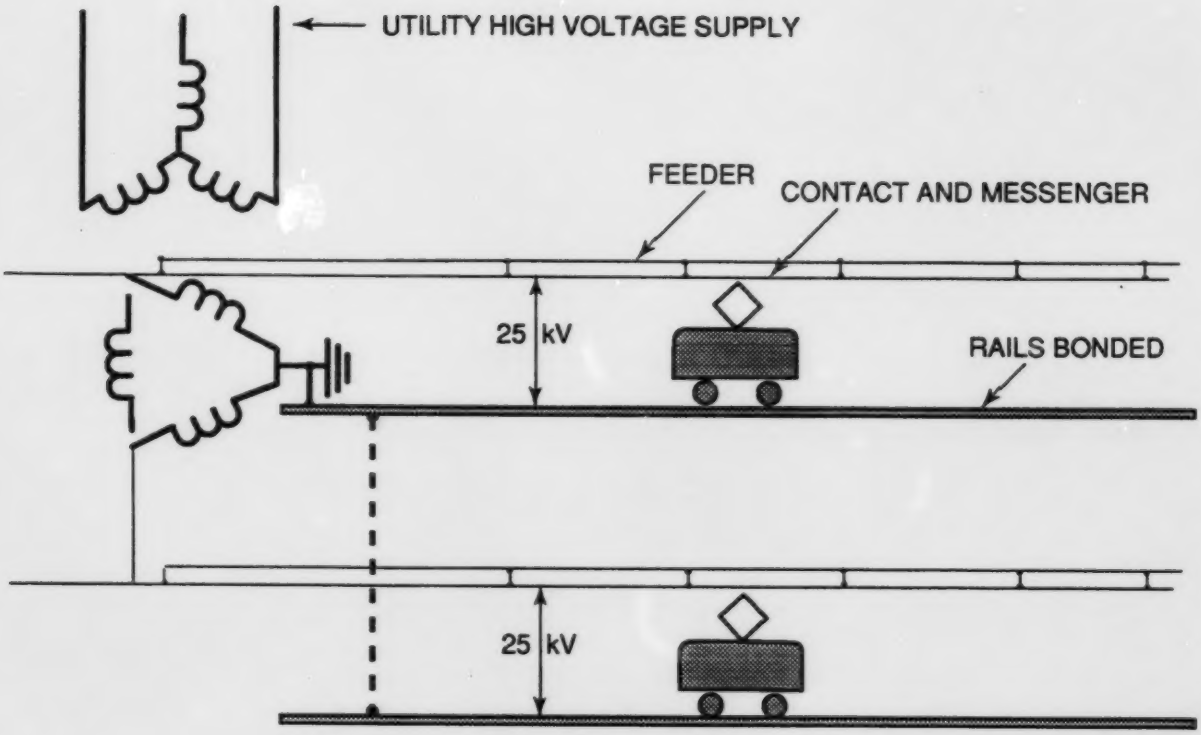
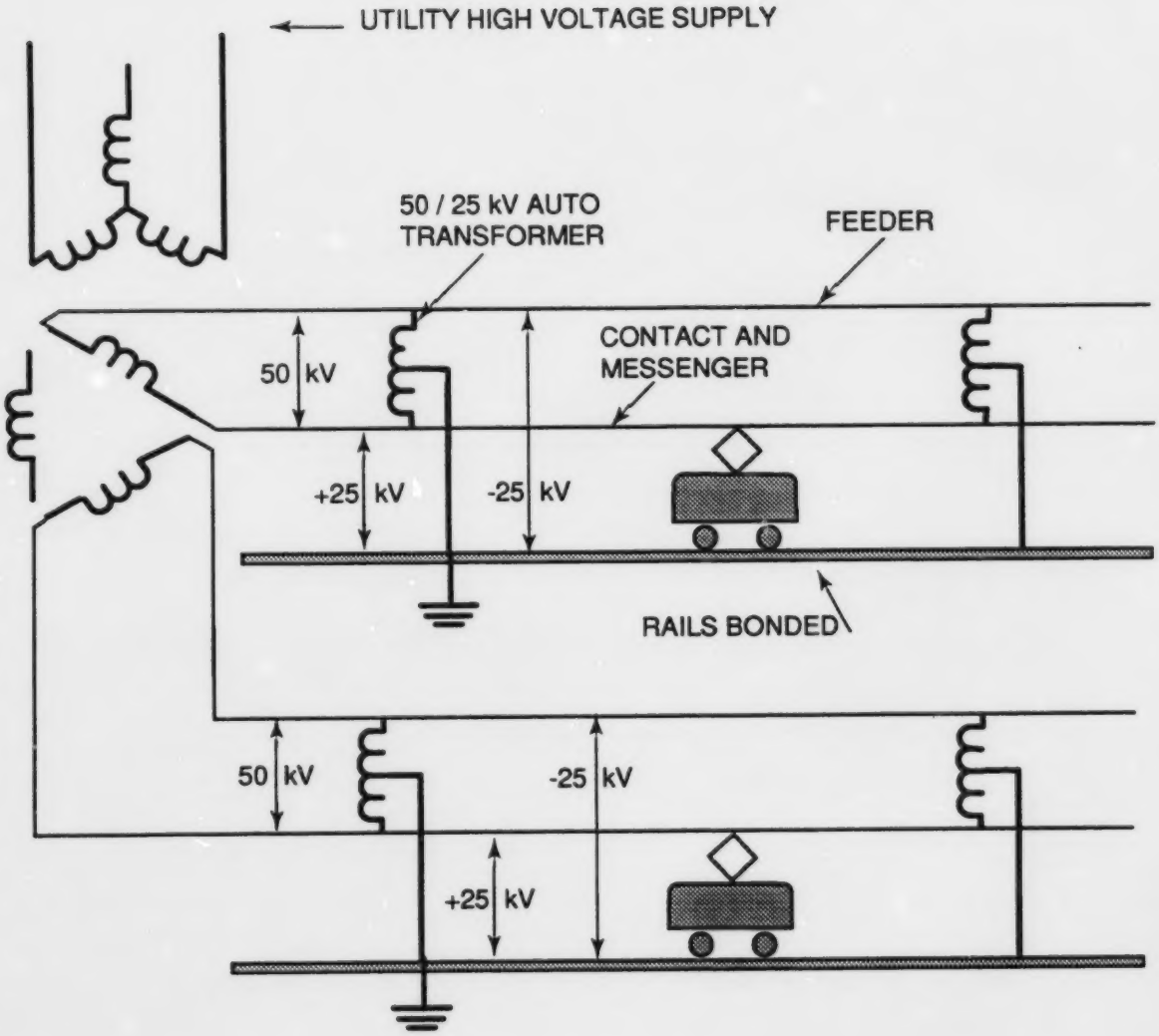


Figure 9.2
+ / - 25 kV SUPPLY
CONCEPTUAL ARRANGEMENT



a loop through the two poles which form a single phase 50 kV system. The main supply is therefore 50 kV, with the exception of the section between the actual locomotive location and the nearest autotransformer.

The +/- 25 kV system has, therefore, a transmission capability close to that of a 50 kV supply, but without the problems of increased clearances appropriate to 50 kV. It also offers the benefit of reduced EMI in parallel communications circuits as the ground loop currents exist only in the sections limited by the autotransformers. From this viewpoint, the system performance is similar to a simple 25 kV system with booster transformers.

50 kV OCS supply has been used for heavy freight line electrifications in Canada and the United States. Both applications involve unusually long single ended supply OCS sections with series capacitors. There is no specific advantage seen for urban or inter-city passenger services. Clearance problems are more difficult to manage with 50 kV. Should CN or CP adopt such system in the future for long haul freight services, locomotives switchable from 25 kV to 50 kV present no technical problem.

9.3 CHOICE OF OCS SYSTEM

9.3.1 Comparison Between 25 kV ac and 1500 V dc

This study supports the conclusions of Section 9.1.2 in discounting use of 1500 V dc for GO Transit electrification.

Specifically, in today's context, it does not adequately (or economically) cater for future

- extension of GO network;
- increase of service
- presence of electric intercity passenger and/or freight service in the corridor

The overhead clearance advantages of 1500 V dc are minimal. The practical voltage component of clearance differs by only a few centimetres and following established construction standards for the two systems, upgraded 25 kV ac systems have generally been pushed through tight clearances originally carrying the 1500 V dc system. In cases such as over-bridges the only visual difference may be new screening to prevent persons approaching the OCS.

Until recently, dc systems offered the only cost effective technology for regeneration of braking energy (Section 8.8.1) but regeneration is now equally viable on modern ac systems.

Finally, the substantially heavier conductors required for the OCS to carry the higher current required at 1500 Volts make these systems extremely obtrusive visually. Energy losses in the rectifier supply stations and in the OCS itself are about double that of a 25 kV ac system in passenger service and the OCS currents become so high in freight and high speed passenger service that limits on train speed or weight would be too small to be practical for future use by CN, CP Rail and VIA.

9.3.2 Comparison Between 25 kV ac and 3000 V dc

The current study places emphasis on conventional one locomotive hauled and relatively heavy passenger trains, and EMU's assembled to form trains of the same passenger capacity. A brief reappraisal of the options between the 3000 V dc and the 25 kV ac seems, therefore, to be relevant.

The first comparison between the two supply systems was based on using equal reliability criteria, namely the requirement for being able to maintain full service with one supply point out of service. This assumption favours the 3000 V dc system with numerous feeder stations.

The second comparison was done for the Lakeshore Line, by performing power demand and voltage profile analyses with the VOLTRAN program. It was found that using 25 kV ac, three trackside feeder stations would be required, one near Union Station and two towards the end of the west and east sections. With any of the three

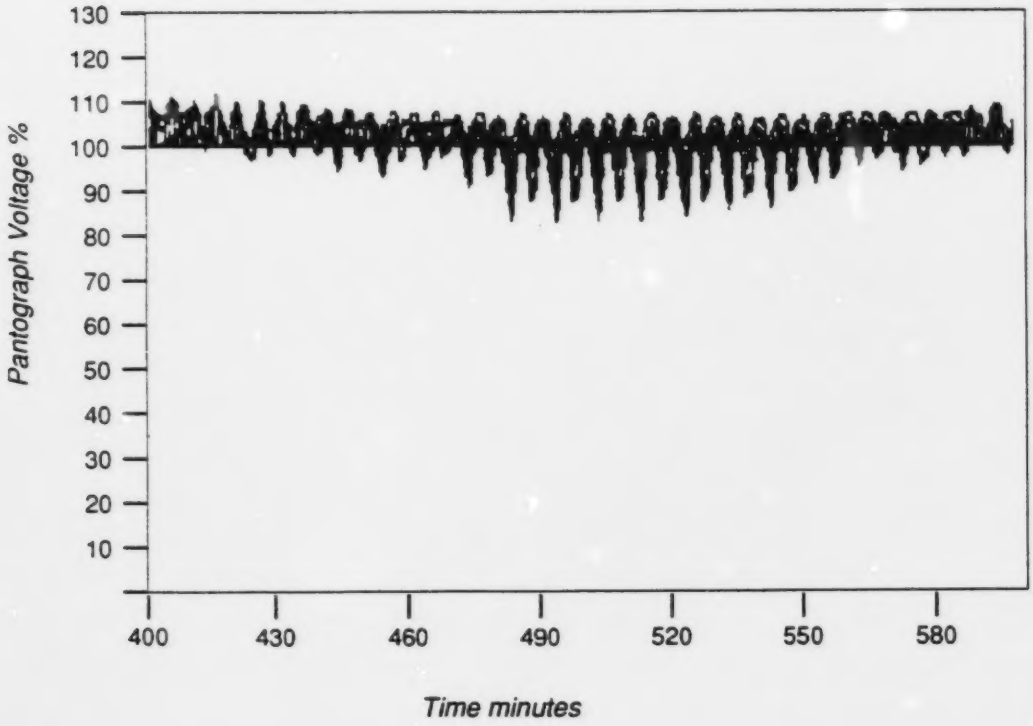
stations out of service full supply can be maintained. In contrast, with 3000 V dc supply, feeder stations would have to be located at intervals of 7.5 km, requiring 15 to 17 feeder stations along the Lakeshore line. These conditions are shown as Figures 9.3 and 9.4 respectively.

The main parameters for the +/-25 kV and 3000 V dc system would be as follows:

	3000 V dc	25 kV ac
OCS MW loading with one supply out of service	6 MW	15 MVA
OCS current rating	2000 A	750 A
Feeder station capacity	12 MW	30/60 MVA
Number of utility supply feeders	15	4
Total feeder station capacity	180 MVA	120 MVA

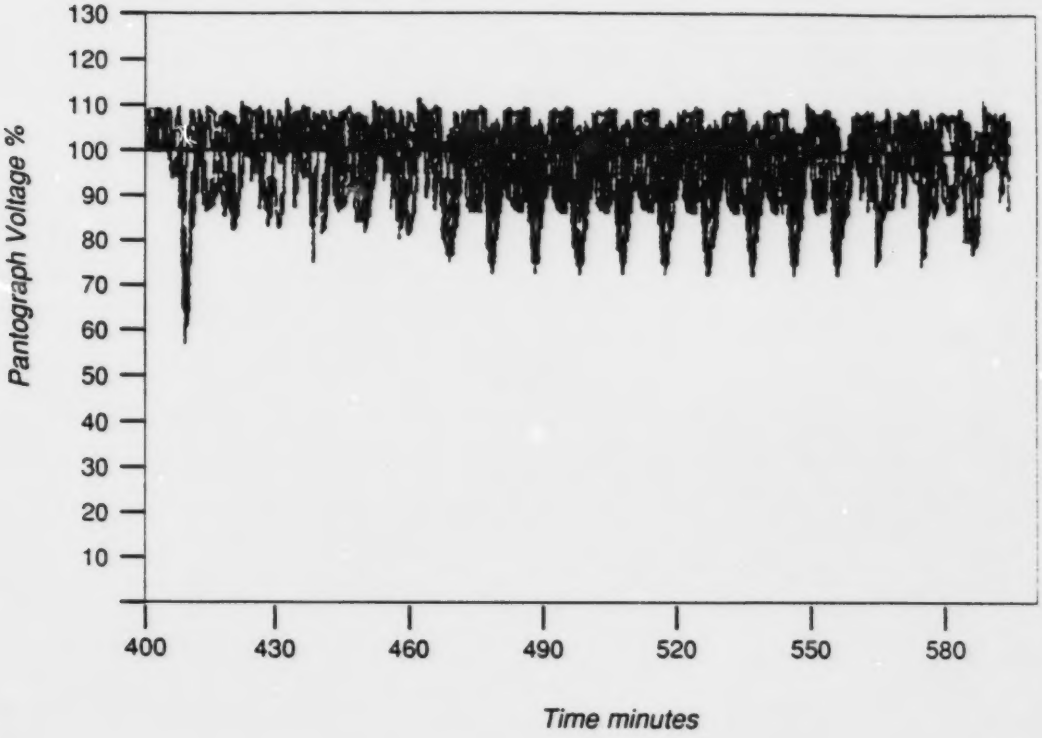
The above comparison clearly demonstrates that the investment in a 3000 V dc system would be substantially higher than in a 25 kV ac system due to the large number of trackside feeder stations and utility feeders to these stations. The higher cost of the 3000 V dc system could be further increased by the cost of corrosion protection measures. It is only in the area of interference with communication circuits where the 3000 V dc system has an advantage. In view of the higher cost of 3000 V dc, the higher inherent capability of the 25 kV system, the flexibility of the 25 kV system to interface with mainline operations, and the more advanced locomotive designs already available with 25 kV, the 25 kV option is recommended as in the previous studies.

Figure 9.3
VOLTAGE PROFILE
Lakeshore Line



+ / - 25 kV System - three feeder stations with one feeder station out of service

Figure 9.4
VOLTAGE PROFILE
Lakeshore Line East Section



3000 V dc System - Feeder stations Spacing 7.5 km with one feeder station out of service

9.3.3 Choice Between Single Pole and +/-25 kV ac

The two options were compared in terms of the OCS parameters and feeder station requirements.

As far as OCS design is concerned the two systems are practically identical. The typical single pole 25 kV system requires the usual contact and messenger wire, and a feeder wire to reduce the OCS impedance. In the +/-25 kV system the feeder wire assumes the role of the second pole. In both systems the clearance requirements are for the 25 kV voltage class. In both cases a separate ground wire is desirable along the whole length of the line.

The single pole 25 kV system requires booster transformers at regular intervals (say 5 km) to reduce interference with communication circuits. The +/-25 kV system requires autotransformers at intervals of about 10 km. The difference in cost in favour of the booster transformers is not substantial.

If the requirement is to maintain full service with one feeder station out, the single pole system would require a feeder station near Union station, and two feeder stations on both east and west sections, a total of five feeder stations. With the +/-25 kV system only three feeder stations are required, one near Union Station, one near Hamilton, and one near Oshawa.

Based on the preliminary cost comparison, the +/-25 kV system would offer a cost saving of about $5 million compared with the single pole 25 kV system. There is no potential disadvantage seen. The technology is mature.

For the above reasons the +/-25 kV system was chosen for the purpose of this study. A more detailed comparison can be made at a feasibility study level for choosing between the two options. The choice has no effect on the rolling stock.

9.4 DESIGN PARAMETERS OF THE +/-25 kV SYSTEM

The design parameters given in this section are strictly for the purpose of arriving at pre-feasibility cost estimates, and should only be used in this context.

9.4.1 OCS Design

Detail designs of overhead contact systems (OCS) have evolved to suit several complex parameters; most notably:

- physical strength under wind and ice;
- vertical (and horizontal) resilience during the passing of train pantographs;
- minimal wear;
- expansion and contraction with temperature changes;
- insulation of high voltage;
- corrosion resistance;
- ease of installation;
- ease of maintenance;
- minimal environmental (visual) impact.

Over a single track the hinged cantilever type of support is widely adopted (Figure 9.5). The relatively heavy insulators can be placed close to the pintle hinges or (at lower voltages) used as pintles. This also minimizes any locomotive soot deposit on diesel routes. Hinging permits free movement of the wire at constant tension under temperature change. Hinging also assists off-track assembly of cantilevers and avoids direct longitudinal and torsion stresses on the pole (these stresses are limited to those from other pole mounted conductors).

Poles may be round, solid, tubular, flanged beams or fabricated. But in general, the optimum is an unguyed pole with over track cantilever bending strength greater than track longitudinal strength and graduated with vertical height. In this respect round poles of wood, steel, concrete are inefficient. Wood must be guyed for stability. Ideally, guying is only used as a last (but effective) resort in unstable ground or for quickly rigged temporary poles after major derailment damage. The consultant has

achieved excellent structural efficiency with a fabricated galvanized steel pole which also has unobtrusive visual impact. OCS assembly is ideally based on fully adjustable slip-jointed and clamped components. This is also facilitated by optimum pole design.

A wide range of techniques for creating pole foundations and setting poles has been used. In general, the pole sites fall within the consolidated ground forming the edge of the railway subgrade. In theory, augering, placing a long pole into the hole and filling much of the hole with mass concrete offers a simple solution. In practice the above technique requires careful pole alignment and no subsequent adjustment. And not all ground can be deep augured.

The Consultant generally prefers to flange steel poles just above ground level to achieve several installation and maintenance benefits:

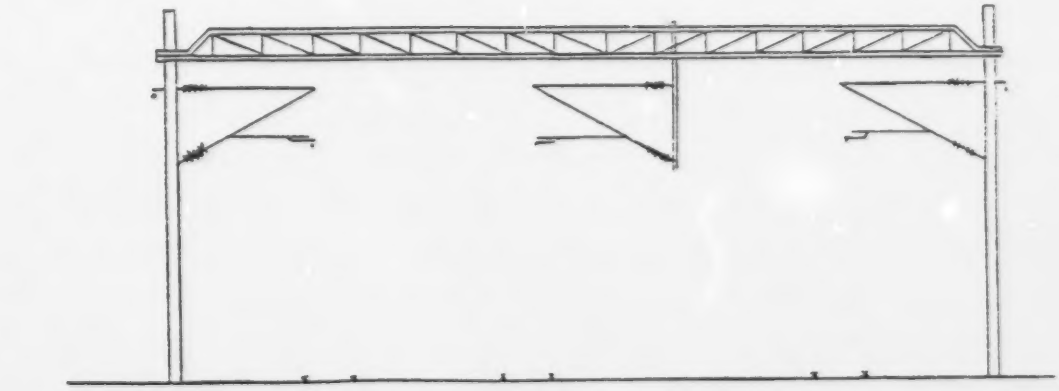
- the manufactured length of the pole is reduced;
- a wide range of deep and shallow foundation designs are equally applicable provided only that four bolts can be placed through the pole flange;
- pole vertical alignment can be adjusted.

Foundation excavation by auger or clamshell digger is still a much used technique but the Consultant participated in one of the first large scale applications of driven pile foundations. The steel beam pile is cut off to datum level just above ground and a levelled steel flange welded onto it. At the detail design and construction bidding stages of railway electrification, it will be found advantageous to put one or more alternative foundation designs before each competing contractor.

As described above, the hinged cantilever carried by one pole is optimum for single track. For double track the same arrangement with poles down each side is optimum. For standard railways a single row of poles between the tracks is rarely seen because of the wider subgrade and outside structure clearances required especially as to be compatible with freight movements. For three or more tracks the

Figure 9.5
SINGLE TRACK CANTILEVER

Figure 9.6
MULTI TRACK PORTAL



optimum is usually heavy weight poles at the extreme outsides with either a light-weight truss or a cable headspan spanning all tracks. The consultant prefers the truss (or portal) style for mainline trackage (Figure 9.6) because:

- cantilever forces on the poles are much reduced;
- the over-track catenary hardware is identical to that used on single cantilever poles and the dynamic adjustment of each over-track catenary is independent of the others.

Headspan suspension can be cost effective across storage sidings where only single (trolley-wire) type OCS is needed.

Longitudinally (along the track) OCS construction (Section 1.2.3 refers) follows a modular pattern as far as possible. The contact wire is deliberately staggered off track centre at each pole (zig-zagged) to sweep the working width of the pantograph and so even out pantograph wear. Due allowance is made for locomotive roll, cross winds, etc. The metallic carbon strip across the top of the pantograph is considered expendable. Contact wire wear is negligible. The wire may last many decades.

Optimum pole spacing is about 70 metres on straight track. On curves this is reduced so as to maintain standard stagger of each chord of contact wire across track centre line: cantilever adjustment is also required to match superelevation (tilt) of track and locomotive. It is possible to incline the droppers between messenger and contact wire and so curve the contact wire but this specialized construction is not favoured for mainline OCS where consistent dynamic performance and ease of maintenance are paramount.

Allowance for expansion in northern latitudes has created an optimum OCS length of about 1.4 kilometres. In such a length the mid-point is anchored longitudinally and weights moving vertically maintain tension at each end. Sections overlap side by side for one pole span so allowing smooth transition of the pantograph. Side by side rigging of catenary over track-turnouts again provides smooth pantograph transition without any need for mechanical turnouts in the contact wire or impediments to free expansion and resilience.

Due to the modular nature of OCS construction, preliminary costing on a "per single track kilometre" basis is satisfactory. Detail costing is later derived from computer generated tabulations according to detailed track layouts of sub-assemblies and sub-sub-assemblies. As far as possible, assemblies are ordered pre-packaged at place of manufacture and related computer tabulations are used at each pole site and construction stores.

In 1982, the Consultant introduced into Canada a complete series of designs of OCS components based on mature economical Northern European experience and has found Canadian manufacture to be efficient and fully satisfactory in service. Indeed these fabricated and cast metal components are within the capability of very many Canadian manufacturers therefore offering cost effective local involvements in electrification.

It is assumed for the purpose of costing that regardless the type of structure used to support the contact system, there will be an independent +/- 25 kV OCS system for each track, except in stations, yards on sidings. The ground return, however, could be common for two tracks.

The wire sizes used for costing are:

• Contact wire	107 mm^2 copper
• Messenger wire	107 mm^2 bronze
• Feeder wire	240 mm^2 ACSR (SCA)
• Ground return	240 mm^2 ACSR

OCS design, and clearances should conform to Canadian Standard C22.3 No.8-M91 1991.

9.4.2 Trackside Feeder Stations

For the purpose of preliminary estimates it is assumed that a central feeder station is constructed in the vicinity of Union Station, feeding both ways the Lakeshore line and feeding the Richmond Hill, Stouffville, Barrie, Guelph and Milton lines.

In addition to the Union Station substation, trackside feeder stations will be required near Hamilton, Oshawa and near the other line ends. The power supply with this arrangement should have a reliability equal to the Ontario Hydro regional distribution system. As explained further in Section 9.5.1, the railway system has designed redundancy to overcome a localized power failure, whether caused by Ontario Hydro or Railway equipment defect.

The Union Station feeder station will have two 50 MVA transformers fed from Ontario Hydro downtown substation. The feed could be 115kV or 230 kV, depending on the Ontario Hydro supply voltage. The details of the feeder station are discussed in Section 9.5.

The feeder stations at Hamilton and Oshawa would have single transformers rated at 30 MVA, supplied by Ontario Hydro or the area municipal utility at a suitable voltage level. The other line end feeder stations require smaller transformers, but for reasons of standardization these stations may be identical to the Oshawa and Hamilton feeder stations. These stations are also discussed in detail in Section 9.5.

In addition to the transformers, and switchgear required for switching of OCS sections and protecting transformers and OCS feeders, harmonic filters will be required to satisfy the harmonic pollution criteria set by Ontario Hydro. 3rd, 5th, 7th and high pass filter may be installed, depending on the locomotive characteristics.

The individual OCS section loads reflect as single phase loads into the utility system and cause a voltage distortion which is measured by the 'negative sequence' voltage. Too high a distortion could cause damage to customer's induction motor drives. Ontario Hydro has a strict limitation on the negative sequence voltage generated. The tolerated limit is 1%. The distortion caused is a function of the short circuit level at the utility interface, and the degree of the railway load unbalance on the three phases. This would have to be examined in detail in a feasibility study. Preliminary estimates indicate that with the relatively large number of feeders at the Union Station supply point, the unbalance will not exceed the limits. Nonetheless, some allowance should be made in the cost estimates for phase balancing.

9.5 POWER SUPPLY TO THE OCS

9.5.1 Capacity and Location of Feeder Stations

Capacity of the substations are selected to allow for extended outage of any power equipment without adverse effect on train operations.

The central substation at or near Union Station is sized to supply the Lakeshore line and at least one other line, with the outage of any one of the main transformers (50/67 MVA). If the entire Union Station is out of service, the Lakeshore lines could still be fed from their end stations at or near Hamilton and Oshawa (30/40 MVA transformers each).

All the other lines could also be fed from their end substations (10/13 MVA single phase or 30/40 MVA, 3 phase transformers). The system is designed with sufficient built-in and energized spare capacity to allow for several simultaneous contingencies to be catered for. Further refinements of the system parameters need to be addressed in a reliability assessment during the basic design stage of the project.

The trackside auto-transformer (AT) stations will be spaced approximately every 10 km along the railway right of way. The 50/25 kV, 5 MVA auto-transformer centre point is grounded directly, as well as through a 3 kV metal oxide varistor to protect against over-voltages.

The auto-transformers will be protected by a metalclad switchgear (25 kV) with either fused disconnects, or vacuum, or SF_6 breakers depending on control and protection philosophy, which shall be established during the basic engineering design.

Switching and paralleling stations will be combined with the trackside AT stations where required by the track layout. The SF_6 or vacuum single phase traction breakers will be included in the metalclad switchgears.

9.5.2 High Voltage Supply to Feeder Stations from Ontario Hydro and/or Municipal Utilities

The GO Transit Electrical System is planned to be fed from a new substation located at or near Union Station. The high voltage supply to this substation will be via underground cables from an Ontario-Hydro substation approximately 400 metres away. Each of the seven lines in the system may also be fed from substation located at the end of the lines and supplied by the applicable municipal Hydro.

The Figures shown are overall conceptual design arrangements and as such they do not reflect detailed engineering work. Numerous engineering studies will have to be made during the basic and detailed engineering phases of the project, before any of these concepts may be firmed up.

Each line will have to be studied individually for: power demand, voltage profile, load flow, load unbalance, harmonic analysis, system control and data acquisition (SCADA) and protection coordination.

Safety guide lines shall be established for grounding and bonding, allowable touch and step potentials along the railway right-of-ways and substations.

Electromagnetic interference (EMI) and compatibility (EMC) shall be investigated on each line individually. Specific attention should be given to potential interference problems with telecommunication systems and pipelines occupying joint corridors with electrified railways.

9.5.3 Feeder Station Single Line Diagrams

The attached single line and layout diagrams, show:

- the proposed system configurations for Figure 9.7;
- the main feeder station near Union Station, Figure 9.8;
- the single line of typical substations, Figure 9.9;
- the conceptual layout of Hamilton substation, Figure 9.10.

The transformer capacities have been discussed in earlier sections.

The circuit breakers may be SF_6 or vacuum breaker type, 2 poles or 3 poles as shown.

Figure 9.7
PROPOSED SYSTEM CONFIGURATIONS

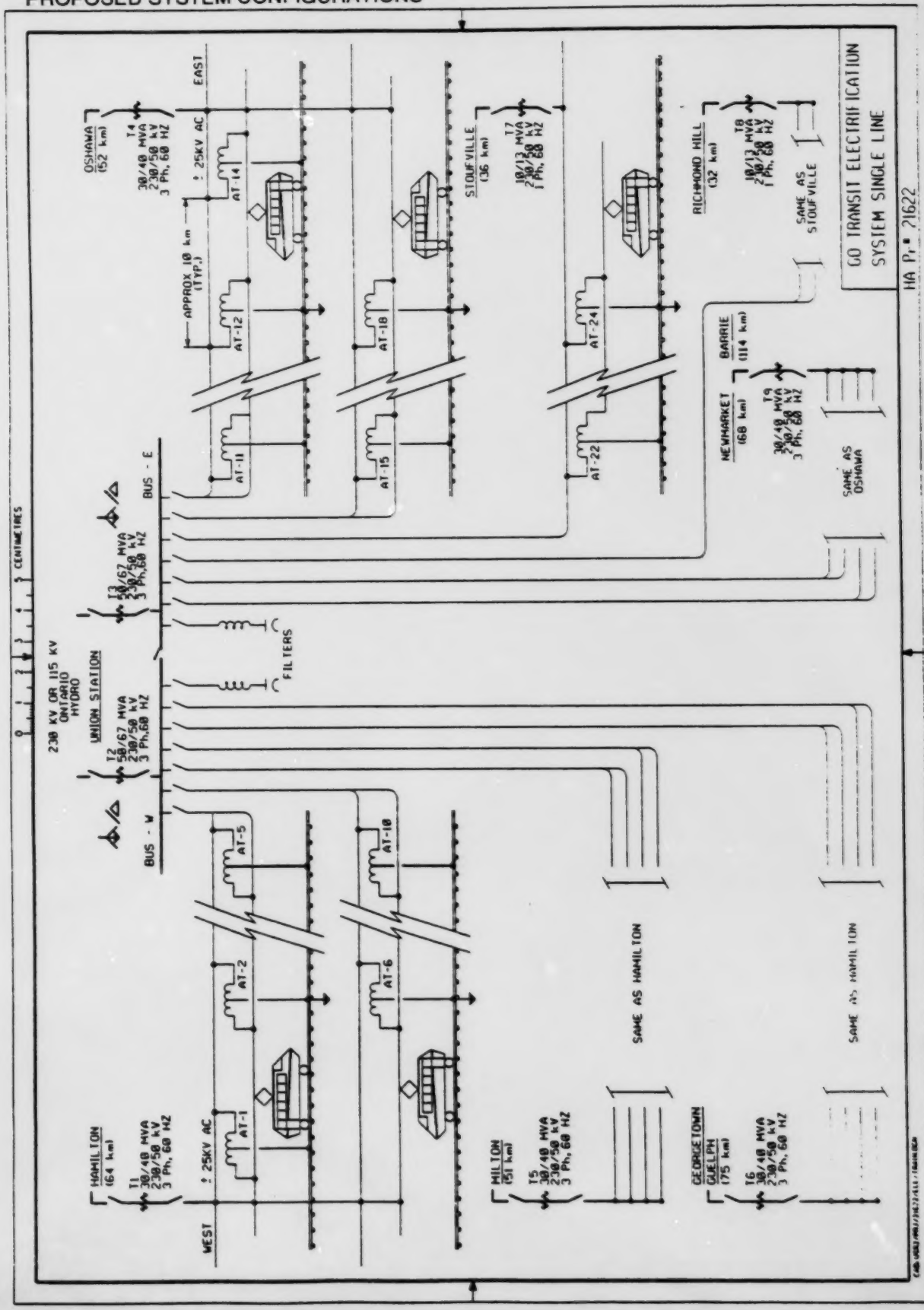


Figure 9.8
MAIN FEEDER STATION NEAR UNION STATION

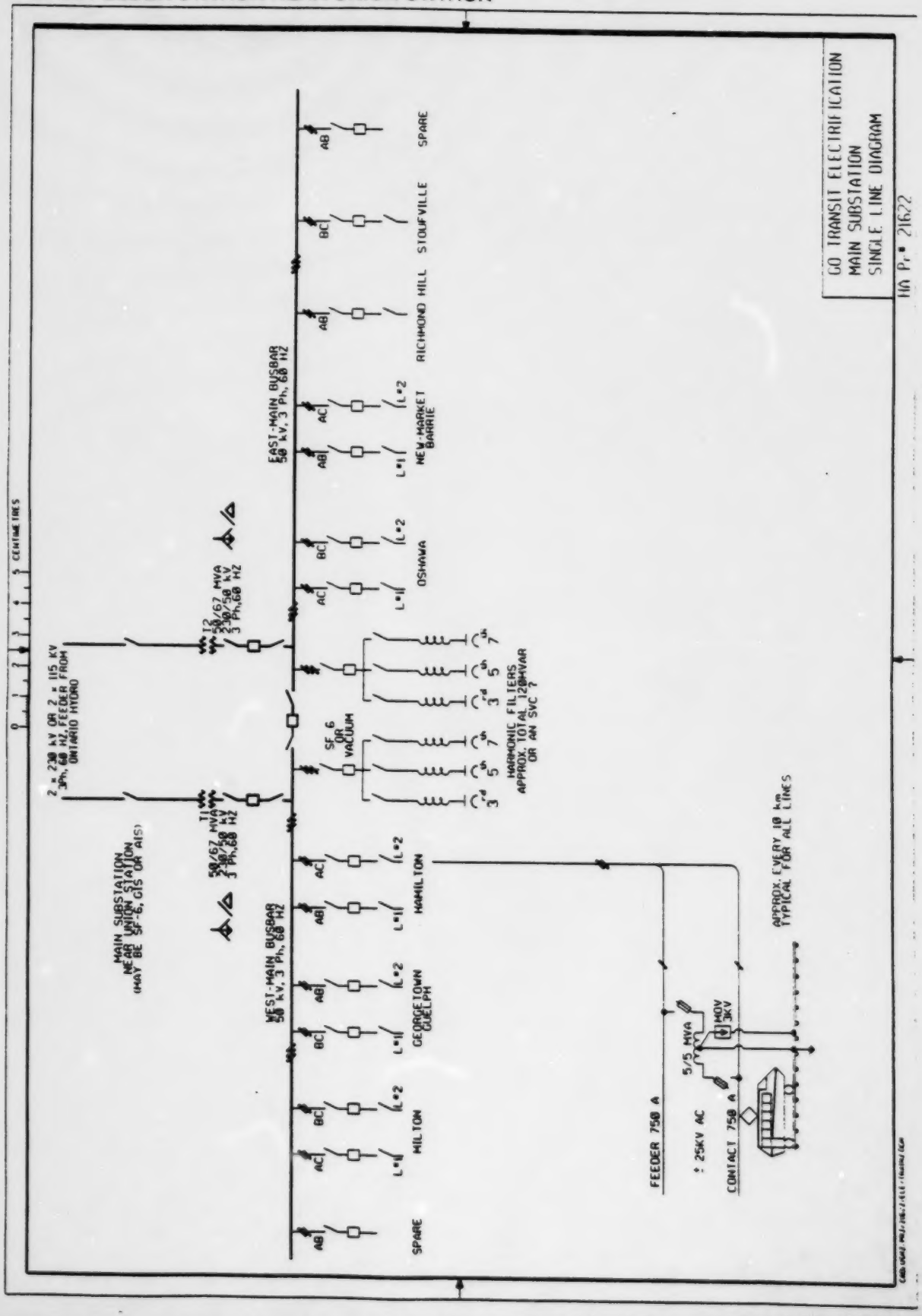


Figure 9.9
SINGLE LINE DIAGRAM OF TYPICAL SUBSTATIONS

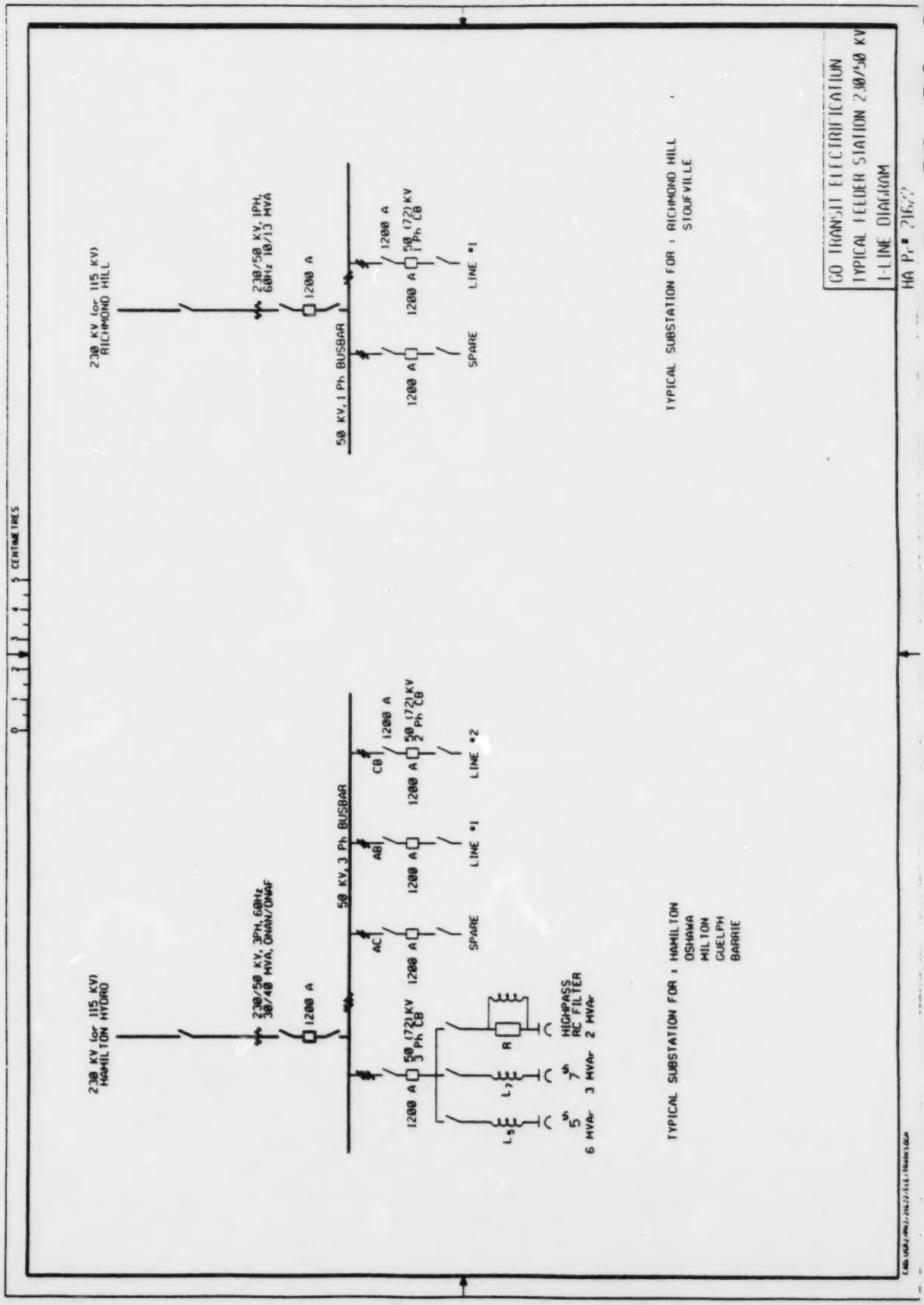
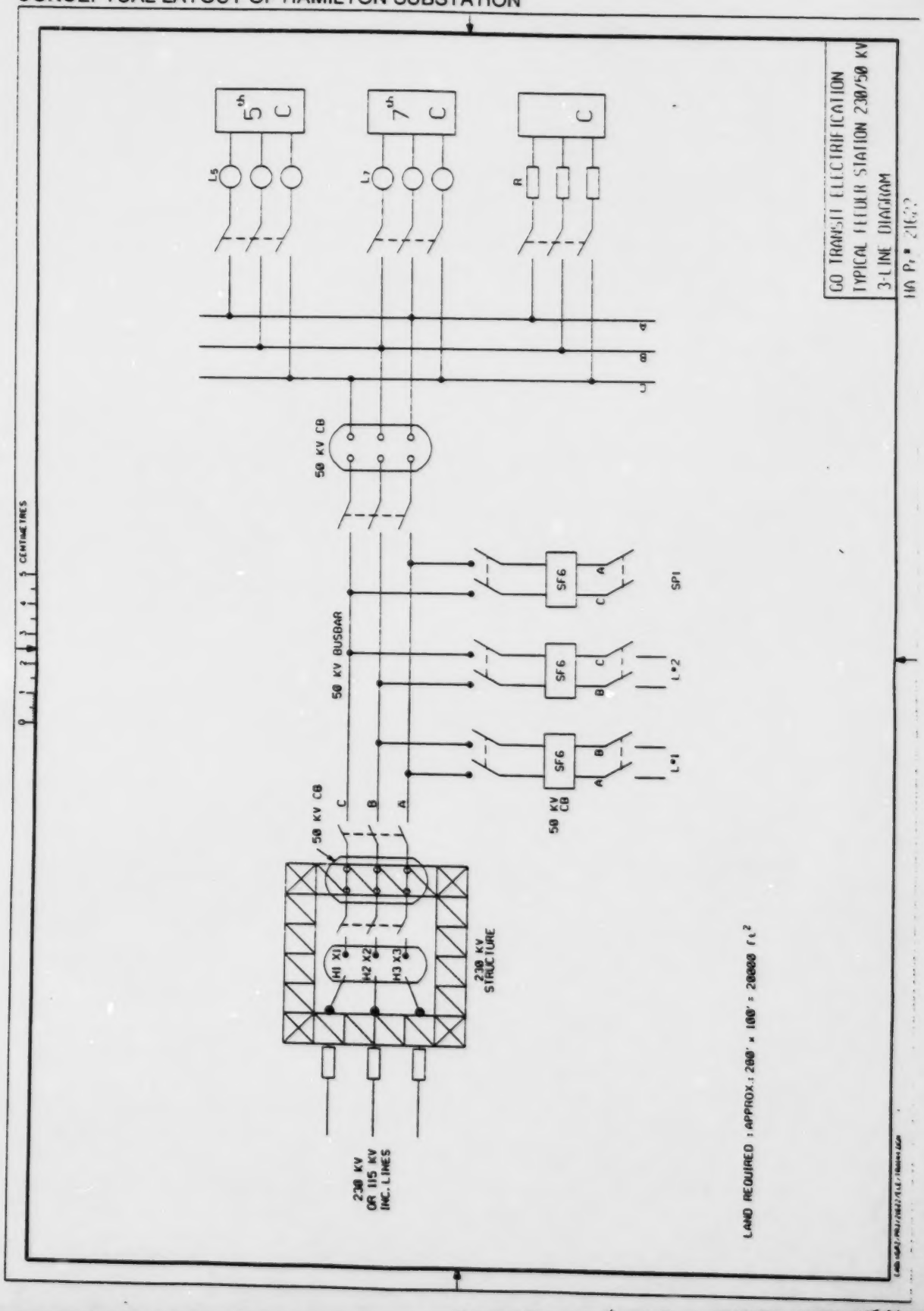


Figure 9.10
CONCEPTUAL LAYOUT OF HAMILTON SUBSTATION



9.6 COST ESTIMATES

9.6.1 Estimated OCS Costs

The railways proposed trackage expansions have been taken into account in the development of estimated OCS costs. Table 9.1 below summarizes the proposed trackage expansions and also indicates the number of electrified tracks considered necessary by the Consultant for flexible operation of GO trains by the host railways. In general, the number of electrified tracks does not exceed three (3) except at locations of predictable congestion and/or layover.

TABLE 9.1

Estimates for Equivalent Single Track Length Electrified

Union Stn. - Hamilton	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR	0.0	1.1	1.1	13	7	7.7
Oakville Sub.	1.1	6.2	5.1	6	4	20.4
	6.2	20.9	14.7	4	3	44.1
	20.9	21.9	1.0	5	5	5.0
	21.9	30.0	8.1	4	3	24.3
	30.0	31.0	1.0	5	5	5.0
	31.0	35.0	4.0	4	3	12.0
	35.0	38.0	3.0	3	3	9.0
	38.0	40.0	2.0	2	2	4.0
TOTAL MILES						131.5
TOTAL KILOMETRES						211.7

Union Stn. - Oshawa	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR	333.8	332.4	1.4	13	7	9.8
Kingston Sub.	332.4	325.2	7.2	6	4	28.8
	325.2	314.0	11.2	4	3	33.6
GO Sub.	314.0	301.0	13.0	2	2	26.0
TOTAL MILES						98.2
TOTAL KILOMETRES						158.1

TABLE 9.1 (cont'd)

Union Stn. - Milton	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR Galt Sub.	0.00	1.10	1.10	13	1	1.1
	1.10	4.32	3.22	2	2	6.4
	4.32	4.94	0.62	3	3	1.9
	4.94	6.64	1.70	4	4	6.8
	6.64	18.86	12.22	3	3	36.7
	18.86	24.17	5.31	2	2	10.6
	24.17	27.58	3.41	3	3	10.2
	27.58	31.34	3.76	2	2	7.5
	31.34	32.10	0.76	3	3	2.3
TOTAL MILES						83.5
TOTAL KILOMETRES						134.5

Union Stn. - Guelph	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR Weston Sub.	0.0	1.6	1.6	13	0	0.0
	1.6	10.5	8.9	2	2	17.8
	10.5	14.0	3.5	3	2	7.0
	14.0	15.0	1.0	4	4	4.0
	15.0	17.0	2.0	3	3	6.0
Halton Sub.	11.1	24.1	13.0	4	3	39.0
Guelph Sub.	30.1	48.0	17.9	1	1	17.9
	48.0	49.0	1.0	2	2	2.0
TOTAL MILES						93.7
TOTAL KILOMETRES						150.9

Union Stn. - Barrie	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR Newmarket Sub.	0.0	1.6	1.6	13	0	0.0
	1.6	42.5	40.9	2	2	81.8
	42.5	53.5	11.0	4	2	22.0
	53.5	60.5	7.0	1	1	7.0
	60.5	63.0	2.5	1	2	5.0
TOTAL MILES						115.8
TOTAL KILOMETRES						186.4

TABLE 9.1 (cont'd)

Union Stn. - Stouffville	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
Kingston Sub. Uxbridge Sub.	328.6 61.0	325.2 42.0	3.4 19.0	0 2	0 2	0 38
TOTAL MILES						38
TOTAL KILOMETRES						61.2

Union Stn. - Richmond Hill	from Milepost	to Milepost	length (miles)	Total Tracks	Proposed Elect. Tracks	Total Miles
TTR Bala Sub.	0 1.9 15.4	1.9 15.4 22.2	1.9 13.5 6.8	13 2 3	0 2 3	0.0 27.0 20.4
TOTAL MILES						47.4
TOTAL KILOMETRES						76.3

As noted in Section 9.4.1 it is reasonable to estimate costs on a 'per single track kilometre' basis. Due to the frequent presence of crossovers for multi-track operating flexibility the track kilometre basis must be adjusted to allow for this additional infrastructure. The Consultant has allowed for 10% above the single track kilometre basis.

Most, if not all components can be manufactured in Canada (and in Ontario) to the designs specified in Section 9.4.1.

Statistics Canada indices have been used to adjust earlier labour and material category costs for the preliminary estimate of OCS per single track kilometre shown in Table 9.2.

TABLE 9.2

	Low Estimate ($000's)	High Estimate ($000's)	Average ($000's)
Material per single track kilometre	66.5	91.0	78.7
Labour per single track kilometre	36.5	52.5	44.5
TOTAL	103.0	143.5	123.2

Table 9.3 presents the estimated OCS capital costs for the electrification of the GO Transit network using the average cost developed in Table 9.2.

TABLE 9.3

Corridor	Adjusted Track Kms	OCS Cost $ million
Union Stn. - Hamilton	233	28.7
Union Stn. - Oshawa	174	21.4
Milton	148	18.2
Guelph	166	20.4
Barrie	205	25.3
Richmond Hill	84	10.3
Stouffville	67	8.3
Workshops		
Willowbrook	12	1.5
Other Sites	12	1.5
SUB-TOTAL	1,101	135.6
Contingency Allowance @ 25%		33.9
SUB-TOTAL		169.5
Engineering @ 15%		25.4
GRAND TOTAL		194.9

9.6.2 Cost of Feeder Substations

The following Table 9.4 presents the estimated cost of providing feeder substations and related equipment for the electrification of the GO Transit network.

TABLE 9.4

Estimated Cost of Feeder Substations
($000s)

Substation	Labour	Material	Other (2)	Total
Main Substation				
Toronto (1)	1,260	5,640	500	7,400
Feeder Substations				
Hamilton	422	1,766	400	2,588
Milton	422	1,766	400	2,588
Georgetown	422	1,766	400	2,588
Oshawa	422	1,766	400	2,588
Newmarket	422	1,766	400	2,588
SUB-TOTAL	2,110	8,830	2,000	12,940
Feeder Substations				
Richmond Hill	275	1,010	300	1,585
Stouffville	275	1,010	300	1,585
SUB-TOTAL	550	2,020	600	3,170
Auto Transformer and Paralleling Station (3) (73 locations)	7,707	18,250	0	25,957
SUB-TOTAL	11,627	34,740	3,100	49,467
Contingency Allow. @ 25%				12,366
Engineering @ 15%				9,275
TOTAL				71,108

NOTES: (1) Includes provision for supervisory Control Room

(2) Provision for Utility connection charge

(3) Auto Transformers at approximately 10 km spacing.
Paralleling switches to suit number of tracks served.

9.6.3 Utility Connection

Provision is made in Table 9.4 for Utility connection charge for connection and circuit protection made within one kilometre. However the "connection charge" should be clearly understood and negotiated in relation to any contracted power tariff. Public Utilities elsewhere have proposed to recover up-front the full capital costs for necessary connection switchgear, busbars and control apparatus in their substations. Depending on the Utility substation's original "expansion" plan, these costs can exceed 50% of the connected railway substation cost.

9.7 OPERATING RULES AND SAFETY TRAINING

Large scale electrification in the USA and limited electrification in Canada quite early in the 20th Century built up a code of practice in parallel with the non-electrified railway code of operating rules. This has most recently been revised in Canada for BC Rail (British Columbia) and is applied as supplemental rules and safety practices for "Electrified Territory". Every employee who works within or passes through electrified territory holds the rule book but not all employees are trained and examined on all sections. For example, distinct specific sections apply to enginemen, maintenance of way, etc. Embodied in the rules are certain safety procedures known equally to electricity utility workers for the same voltage ranges: Basic consistency is essential, so in event of an emergency all authorities know the same steps to follow.

Introduction of the Electrified Territory rules should be part of graduated training classes. It has been found desirable that every involved employee (up to General Manager) receive some basic orientation classes and safety training. This is because although hazards are not difficult to manage and although inherent system safety is very high, few people outside the electricity utilities are familiar with the behaviour of high voltage electricity systems under normal and "fault" conditions. It simply does not (knowingly) appear in everyday life. (This is perhaps a good reflection of the high standards of safety and performance achieved in electricity distribution.) Such basic awareness is desirable to support the faithful execution of safety rules and practices.

Public awareness is another important aspect of safety training. In this case it has been considered appropriate to follow closely the local electricity utility safety themes because the public hazards from railway electrification (by OCS) are closely related to existing hazards of overhead wires (see Section 9.8). In BC Rail a distinctive railway cartoon character was introduced for children (and adult) awareness but in fact most of the messages in the cartoons paralleled electricity utility awareness: flying kites, climbing poles, etc.

9.8 SAFETY CONSIDERATIONS OF ELECTRIFICATION

Section 9.7 above notes that employee operating rules and safe practices are well established in the industry. Employee and public protection from hazards closely follows public utility rules. This includes the grounding of all poles and structures near the OCS. At grade crossings ground conductors are provided under the roadway approaches to avoid any possible voltage gradient in long vehicles. Wire height at 7 m well exceeds normal highway structure limits but private and industrial crossings should be protected by a simple steel portal over the approach road. The concern at such crossings arises from possible movements of plant cranes, mine-trucks, logging trucks, etc. of oversize or insecure loading snagging the wire. Even so, as in vehicle/pole highway collisions, the vehicle occupants are inherently safe from electric shock inside their vehicle.

It is also possible to raise the contact wire to 7.5 metre for a particular crossing situation.

Passengers riding in a train under OCS are also inherently safe and shielded by the railway car body even if the OCS drops onto the car.

Because railway substations serve only the specific load represented by electric locomotives, the ac substation line fault detecting and circuit breaking is extremely sensitive to accidental line faults. It can for example, detect faults appearing as "short circuits" which draw less than the normal power of a locomotive.

Where public overpasses are not already wire screened to suppress mischievous rock throwers, it is prudent to install screens over the OCS to suppress wire dangling and short circuit attempts.

9.8.1 Grounding and Bonding

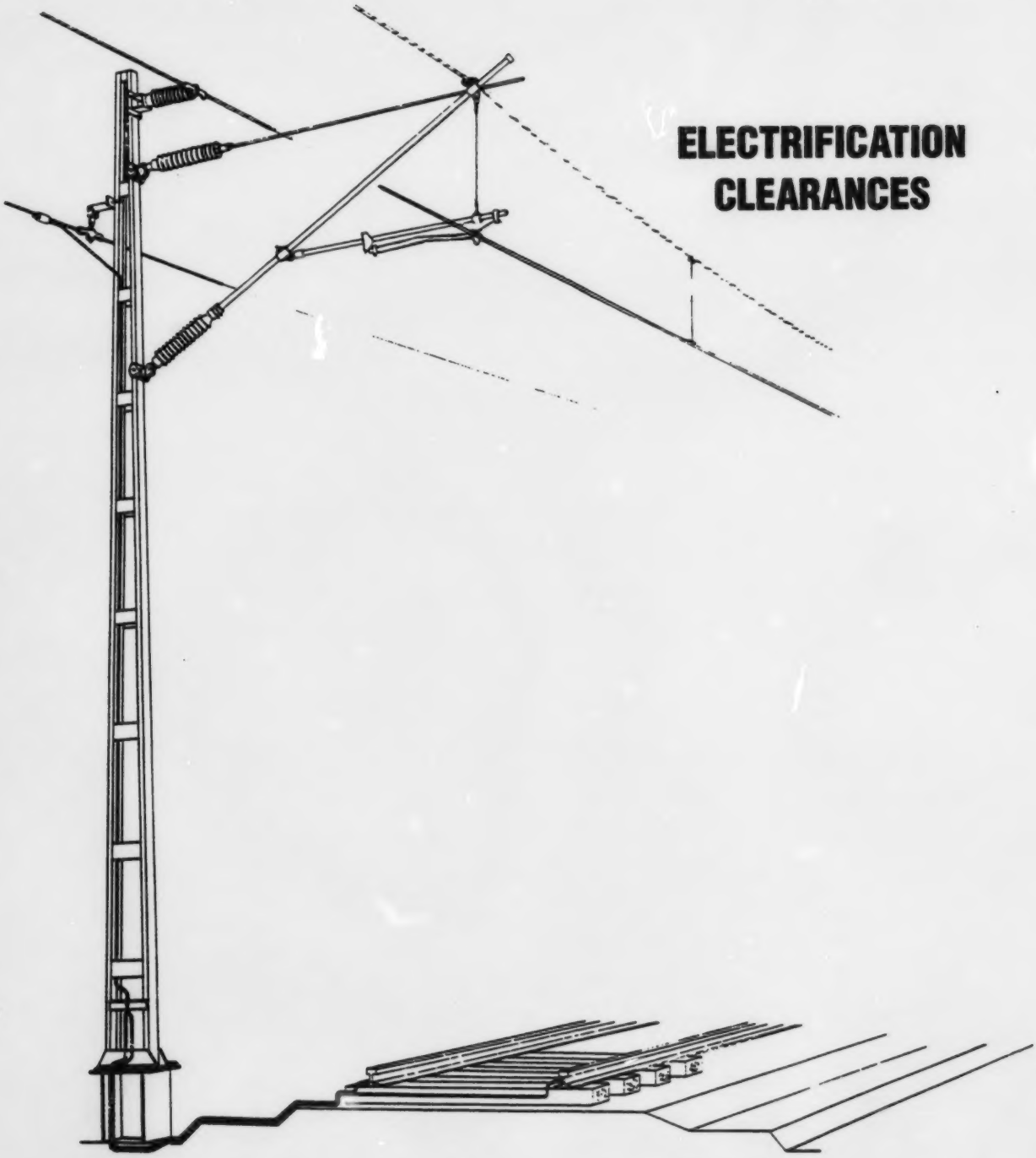
Special design, operating and maintenance procedures must be observed because of proximity to Ontario Hydro's high voltage transmission lines. Hydro towers are often hit by lightning strokes because of their height and the path of least resistance they provide for the discharge current to ground. It is imperative that persons and equipment are protected from these high ground currents discharged during lightning storms or during the occurrence of a ground fault on the hydro lines or on the GO Transit power lines. For a satisfactory level of safety, several low impedance return paths for these faults and load currents that keep step-and-touch potentials within safe limits must be provided. Bonded to this grounding system will be the rails, catenary masts, fencing, metallic station structures and gradient mats. A document such as IEEE's Standard No. 80 (Guide for Safety in Alternating Current Substation Grounding) should be used for appropriate guidelines and limits when designing the grounding system.

It is suggested that a grounding study be carried out which verifies step-and-touch potentials for the project. Based on this study, a comprehensive set of design standards can be developed for use by all design consultants during the detailed design phase of the project.

These standards would include recommendations on the methods of protection and the ways in which they could be implemented.

10.

ELECTRIFICATION CLEARANCES



CPCS Ltd. in association with Hatch Associates Ltd.

10. ELECTRIFICATION CLEARANCES

This section addresses the subject of electrification clearances for the various railway lines where GO Transit now operates or may operate in the future. Since vertical clearance requirements for electrified lines are greater than those for non-electrified lines, the possible need to increase vertical clearances at many locations could introduce significant additional costs to an electrification project, affecting the overall economic viability of the project. Lateral clearance requirements fall within existing non-electrified clearance standards.

The basic assumptions used for this examination of electrification clearance requirements are:

1. Electrification using an overhead contact system at a potential of 25,000 volts, 60 Hertz.
2. A freight equipment height allowance based on the double-stack domestic container cars used by CN Rail and CP Rail.
3. A passenger equipment height allowance based on GO Transit bi-level commuter cars.
4. An electrical clearance allowance conforming to the applicable CSA guidelines.

This study examined, in detail, requirements for electrification clearances and assessed the existing vertical clearance conditions on all the railway lines which may be electrified. Methods of improving the existing vertical clearances are provided together with preliminary cost estimates for achieving these clearances.

10.1 ELECTRIFICATION CLEARANCE REQUIREMENTS

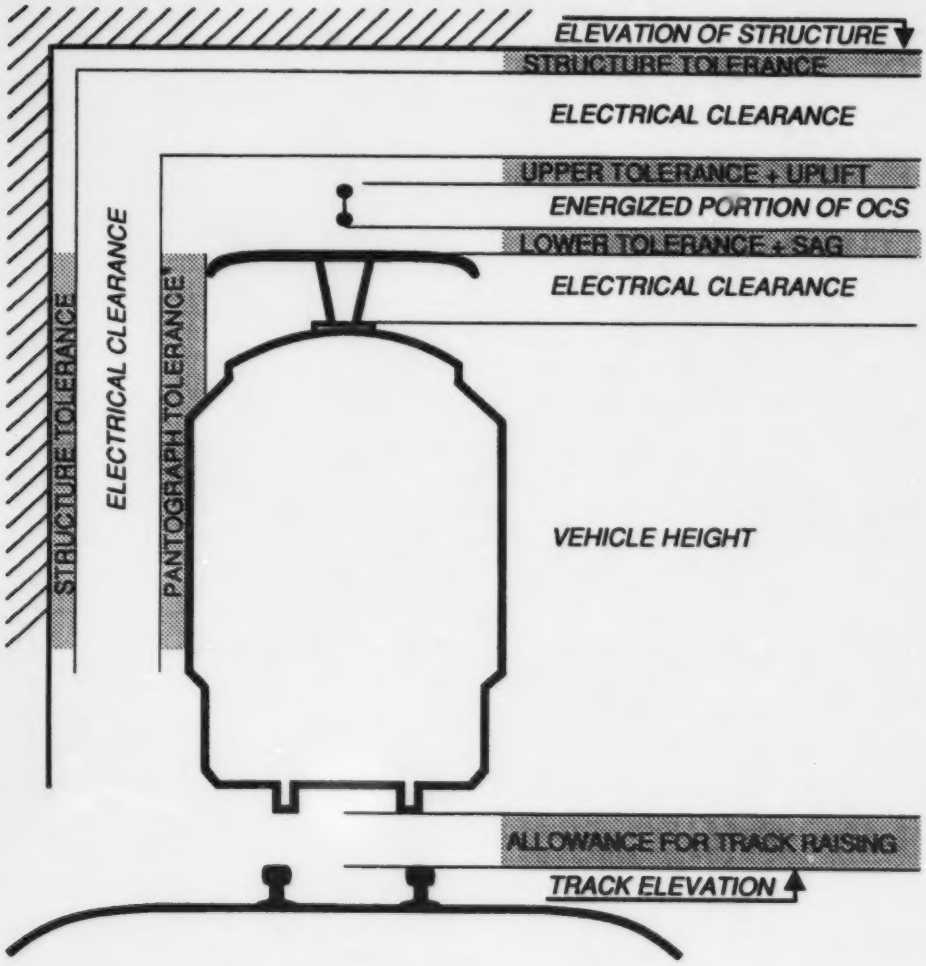
The required minimum vertical clearance between the top of rail and the underside of a structure is found by summing the vertical space requirements of the track, rolling stock, overhead contact system (OCS) and the overhead structure (see Figure 10.1).

TRACK:	- vertical tolerance
	- allowance for track surfacing
	- allowance for frost heaving
ROLLING STOCK:	- vertical dimension
	- vertical dynamic motion
O C S:	- electrical clearance below OCS
	- OCS sag between supports
	- vertical tolerance below OCS
	- live vertical distance
	- vertical tolerance above OCS
	- pantograph uplift of OCS
	- electrical clearance above OCS
STRUCTURE:	- vertical tolerance

Vertical clearances for electrification usually exceed the vertical clearance standards for non-electrified railways.

Adequate lateral clearances must be maintained between the contact pantograph on the electric locomotive, and structures to the side of the track. The minimum lateral clearance requirement (taken from the track centerline) is determined by summing one-half the width of the pantograph, the electrical clearance distance, and allowances for lateral dynamic motion, track superelevation and structure position. Lateral clearance requirements for electrification usually fall within the envelope of normal (non-electrified) lateral clearances.

Figure 10.1
VERTICAL AND LATERAL ELECTRIFICATION CLEARANCES



* INCLUDES ALLOWANCE FOR :
- Track horizontal tolerance
- Track superelevation
- Pantograph sway

10.1.1 AREA Recommended Clearances

The American Railway Engineering Association (AREA) recommends a minimum vertical clearance of 24'-3" (7400 mm) above top of rail for 25,000 volt electrification, based on the following vertical distances:

AREA Electrification Clearance Standards

	(mm)		
Allowance for raising track	305	1'-0"	
Allowance for train height	6400	21'-0"	
Electrical clearance below OCS	270	10.5	(static dimension)
OCS vertical tolerance below	25	1"	
OCS live vertical distance	50	2"	
OCS vertical tolerance above	25	1"	(2 contact wires)
OCS pantograph uplift	50	2"	
Electrical clearance above OCS	270	10.5"	
Total	**7395**	**24'-3"**	

Recommended railway electrification clearances for Canada as set out in CSA C22.3-8 differ only slightly from the AREA guidelines.

10.1.2 CSA Recommended Clearances

The Canadian Standards Association (CSA) guidelines[6] differentiate between static and dynamic clearances. The minimum vertical clearance may be computed for both the static case and the dynamic case - the greater of the two will govern. For vertical clearances, the static case almost invariably governs.

Recommended electrical clearances are derived based on an allowance for transient peak voltages of five times the normal voltage of the power system. Excess transient voltages are discharged through surge arrestors, usually tripping the catenary feed circuit breaker and causing a temporary outage of traction power. If the probability or magnitude of transients can be minimized, then electrical clearances can safely be reduced below those recommended in the CSA guidelines.

10.1.3 GO Transit Clearance Requirements

Following the CSA guidelines, vertical electrification clearance requirements can be developed for both "normal" and "minimum" cases. The "minimum" case takes full advantage of latitude provided in the CSA guidelines to determine the minimum existing vertical clearances which will not impede the installation of the overhead contact system.

CSA Electrification Clearance Standards

	Minimum (mm)	Normal (mm)
Track vertical tolerance	25	300
Rolling stock vertical dim.	(*)	(*)
Electrical clearance below OCS	200	250
OCS vertical tolerance below	50	50
OCS sag	0	15
OCS live vertical distance	50	150
OCS vertical tolerance above	50	50
OCS pantograph uplift	50	50
Electrical clearance above OCS	200	250
Structure vertical tolerance	15	15
Total	**640+(*)**	**1130+(*)**

Applying rolling stock vertical dimensions of 4851 mm for passenger equipment (GO Transit bi-level car) and 6261 mm for freight (CN Rail double-stack domestic container car), the following vertical clearance standards are derived:

Passenger (minimum)	5491 mm	(use 5500)
Passenger (normal)	5981 mm	(use 6000)
Freight (minimum)	6901 mm	(use 6900)
Freight (normal)	7391 mm	(use 7400)

10.1.4 Contact Wire Height

The nominal height of the contact wire above top of rail will be 7000 mm. At locations where vertical clearance is restricted, the height of the contact wire will be

decreased to pass under the obstruction. Contact wire heights for normal and minimum vertical clearance restrictions are as follows:

TABLE 10.1
Electrification Vertical Clearance Standards for GO Transit

	Vertical Clearance (mm)	Wire Height (mm)
No restriction	-	7000
Passenger (minimum)	5500	5135
Passenger (normal)	6000	6485
Freight (minimum)	6900	6535
Freight (normal)	7400	6885

Changes in the height of the contact wire are made using uniform gradients not exceeding 2% relative to the track profile.

10.2 EXISTING CLEARANCE CONDITIONS

With the exception of the platform tracks at Union Station, all GO Transit routes must be available to freight trains. On routes shared with freight trains, a vertical clearance of 7400 mm above top of rail is normally required. This minimum clearance applies to all new overhead construction.

Existing vertical clearances between 6900 and 7400 mm above top of rail will require special engineering of the OCS where it passes below the overhead structure. Existing clearances less than 6900 mm above top of rail must be increased by raising the structure, lowering the track or a combination of these two measures. Where a vertical clearance of less than 6900 mm is caused by a bridge or building, it will usually be less costly to lower the track to improve the clearance. Where the clearance restriction is caused by a light structure such as a signal bridge, it will usually be less costly to raise the structure to improve the clearance.

Both CN Rail and CP Rail have been improving all main track vertical clearances to a minimum of 23'-0" (7000 mm). As a result, most of the existing clearances for older

structures now fall within the range of 6900-7400 mm above top of rail. Most new structures (1985 or newer) have vertical clearances of 7400 mm or greater.

10.2.1 Existing Restrictions

Overhead structures and interferences have been identified along the GO Transit routes studied as follows:

Overhead road crossings	83
Overhead railway crossings	3
Pedestrian overpasses	15
Signal bridges	71
Signal cantilevers	39
Overhead wire crossings	146
Station shed roof	1
Total	**358**

The great majority of road, rail and pedestrian crossings are between 6900 mm and 7400 mm above the track. This also applies to signal bridges and cantilevers, where virtually every structure falls within the 6900-7400 mm range. Clearances between the OCS and wire crossings are governed by a different set of regulations. Although most overhead wire crossings appear to have ample clearance, each location will require re-examination as part of the final design process.

10.2.1.1 Overhead Bridges

The study has identified 19 overhead bridges; 17 road or rail overpasses and 2 pedestrian overpasses, which have less than 6900 mm of vertical clearance above the track. At each of these locations it will be necessary to improve the vertical clearance to at least 6900 mm. None of the structures was seen as a candidate for elimination. For the purposes of estimating costs, it has been assumed that the clearances at road or rail overpasses will be improved through lowering of the tracks, and at pedestrian overpasses clearances will be improved by raising or replacing the structures.

10.2.1.2 Signal Structures

There are presently 110 over-track signal structures, a few of which have vertical clearances of less than 6900 mm. Most of the signal structures have vertical clearances slightly greater than the current freight clearance standard of 7000 mm.

In addition to normal electrification clearance requirements, signal structure clearances are also affected by EMI requirements, signal sight-lines and employee safety considerations. For cost estimating purposes, it was assumed that all signal structures over electrified tracks will be raised to improve vertical clearances, and additionally, will require safety screens to prevent employees from contacting energized portions of the OCS.

10.2.1.3 Station Structures

On tracks used exclusively by GO Transit at Union Station, the most restrictive vertical clearance of 5260 mm (17'-3") exists below the track shed roof over the passenger platforms and platform tracks. Existing clearances over all platform tracks are less than the minimum requirement for electrification of 5500 mm above top of rail. The existence of platforms, passenger subways and a multitude of buried pipes and cables makes lowering of the tracks unfeasible.

Therefore, if CSA criteria govern, electrification through Union Station will require modification of the train shed roof. As noted earlier, if the incidence of peak transient voltages can be controlled, then electrical clearances can be reduced to less than the CSA recommended distances. Another strategy to reduce electrical clearance requirements would be to reduce the system voltage to 12.5 kV within the station. Either of the above techniques will allow electrification under the existing station shed roof, at least on a temporary basis. For the purposes of cost estimation, it was assumed that the existing roof will be demolished and replaced with a new, higher roof.

10.2.1.4 Other Restrictions

In addition to the overhead bridges and signal structures, the rail lines under study are traversed by 146 overhead wire crossings which include communications cables, electrical distribution lines and power transmission lines. These crossings are generally well in excess of 7400 mm above the track. As part of the detailed design of electrification, it will be necessary to confirm that adequate clearances exist at all locations. For the purposes of preliminary costs estimates, this study assumed that no costs will be incurred due to modification of existing wire crossings.

10.3 CLEARANCES - COST IMPLICATIONS

An inventory of all overhead structures along existing GO Transit lines has been made to identify structures with insufficient vertical clearances. Feasible alternatives to provide adequate vertical clearances for each structure type and location have been identified and evaluated. The most feasible method (within the scope of the study) has been established and its cost implications determined.

The following general assumptions have been adopted for the electrification clearance cost estimates:

- All civil work will be carried out by third parties;
- The railway will allow access to each work site at no cost to GO;
- The road authorities will allow access to each site at no cost to GO;
- The railway will provide work trains and crews at GO's expenses;
- All work will be carried out during nighttime (some daytime work would be feasible however);
- Engineering/Architectural services will be provided by third parties;
- All costs are estimated in 1992 Canadian dollars.

10.3.1 Overhead Road and Rail Crossings

Data collected for this study indicated that a total of 19 overhead bridge structures (16 road overpasses, 1 railway overpass and 2 pedestrian overpasses) have insufficient vertical clearance for electrification. Table 10.2 summarizes their locations.

TABLE 10.2
Inventory of Overhead Structures with Insufficient Clearance

Line	Road/Rail Overpasses	Pedestrian Overpasses
Lakeshore West	6	
Lakeshore East	3	1
Milton	1	1
Georgetown	5	
Richmond Hill	1	
Stouffville	0	
Barrie	1	
Total	**17**	**2**

To provide adequate vertical clearances for overhead bridge structures the following alternatives were considered:

- Raise the existing structure by jacking;
- Replacement of structure;
- Locally lower the track;
- Elimination of structure.

Alterations (raising or replacement) to road and rail overhead structures involve considerations such as maintenance of service, modifications to structure approaches and third party ownership and approval. At this stage, it has been assumed that localized track lowering would be the most cost-effective and least complicated method of providing the necessary clearances for road and rail structures.

At locations where lowering of track can be accomplished within the existing ballast section without affecting the track subgrade, the track can be "undercut" using on-track equipment designed for this purpose. As this process does not require removal of the track, it is rapid and relatively inexpensive.

Undercutting costs assume the following methodology:

- Confirm existing ballast depth;
- Take track out of service;
- Remove ballast by undercutting and load into railway cars;
- Unload new ballast from railway cars;
- Align and profile track;
- Return track to service;
- Dispose of old ballast.

The cost of track lowering by undercutting depends largely on the rental cost of the undercutter equipment and the productivity of the operation. Assuming that a single track lowering operation can be carried out per day (up to 400 m track), the cost per track meter is estimated and presented in Table 10.3.

TABLE 10.3
Track Lowering by Undercutting

Item	Units	Lowering Cost/metre
Excavation & Flagging	per metre	$ 66
Track Ballast & Align	per metre	68
Total		$ 134

At locations where the track lowering will affect the subgrade, it will be necessary to remove the track structure to permit excavation, grooming and compacting of the new subgrade surface. Of special concern are the stability of adjacent tracks during the excavation process, and the assurance of adequate drainage of the ballast section after track lowering.

Where the subgrade has to be lowered, the construction procedure to be followed is:

- Take track out of service;
- Dismantle and remove track;
- Remove ballast and load into railway cars;
- Provide temporary shoring to support adjacent ballast;
- Cut down subgrade and load material into railway cars;
- Adjust drainage system as required;
- Level and compact subgrade surface;
- Place layer of new ballast;
- Reinstall track structure;
- Unload additional new ballast from railway cars;
- Align and profile track;
- Return track to service;
- Dispose of old ballast.

The estimated cost per metre of track, to undertake track lowering where subgrade excavation is required is shown in Table 10.4.

TABLE 10.4
Track Lowering by Track Removal

Item	Units	Lowering Cost/metre
Track Removal	per metre	$ 25
Excavation	per metre	83
Shoring/Track Protection	per metre	80
Drainage	per metre	50
Track Replacement	per metre	55
Track Ballast & Align	per metre	97
Flagging	per metre	15
Total		$405

Track lowering is not expected to require extensive shoring to protect adjacent foundations due to the relatively small (less than 600 mm) vertical clearance deficiencies. This should be verified during the detailed design stage particularly where extensive track drainage systems may be present.

The operational constraints necessary for temporary single-track closure to permit track lowering must be considered in the analysis of costs. The length of track affected by lowering at each location has been determined using AREA-guidelines for vertical curves. In the Lakeshore corridor as many as eight separate tracks at each overpass location, would have to be locally lowered to provide necessary clearances. In several instances, overhead structures are close enough together that a single track lowering operation would cover all structures.

The cost estimates shown in Table 10.5 referring to Road/Rail overpasses assume the following:

- Only one track at a time will be taken out of service;
- The railway will provide 8-hour work windows at each site;
- At the end of each work window, the track will be made passable;
- Average production for undercutting estimated at 200 m per day;
- Average production for track removal estimated at 100 m per day;
- There will be no unusually expensive underground interferences;
- Drainage systems will not be affected.

The cost estimates shown in Table 10.5 assume that the undercutting method will be used where track lowering is 300 mm or less. Where track lowering exceeds 300 mm, the track will be lowered using the method of track removal and subsequent replacement. An allowance of $5,000 per structure per electrified track is included to cover security barriers to prevent human contact with the OCS.

TABLE 10.5
Cost of Track Lowering at Overpasses

Subdivision	Mile	Description	Existing Clearance (mm)	Track Lowering (mm)	Track Length (m)	# of Tracks	Lowering cost	Security	Total Cost
Kingston	328.64	Main Street	6575	325	430	4	$696,600	$20,000	$ 716,600
Kingston	326.60	Birchmount	6700	200	360	4	192,960	20,000	212,960
Kingston	321.45	Kingston	6325	575	600	3	729,000	15,000	744,000
Guelph	44.85	Road	6700	200	350	1	46,900	5,000	51,900
Guelph	40.20	Road	6750	150	310	1	41,540	5,000	46,540
Guelph	32.70	Road	6700	200	360	1	48,240	5,000	53,240
Guelph	32.20	Road	6675	225	375	1	50,250	5,000	55,250
Weston	6.12	Rogers Road	6800	100	260	2	69,680	10,000	79,680
Oakville	9.41	Brown's Line	6750	150	310	3	124,620	15,000	139,620
Oakville	3.02	Dowling	6575	325	1525	4	2,470,500	20,000	2,490,500
Oakville	2.85	Jameson	6750	150	(included)	4		20,000	20,000
Oakville	2.69	Dunn	6450	450	(included)	4		20,000	20,000
Oakville	2.38	Dufferin	6450	450	(included)	4		20,000	20,000
Oakville	0.69	Spadina	6700	200	360	8	385,920	40,000	425,920
Bala	8.94	CP Rail	6475	425	510	2	413,100	10,000	423,100
Newmarket	6.40	Road	6500	400	500	2	405,000	10,000	415,000
Galt	14.17	Dundas	6850	50	190	3	76,380	15,000	91,380
Lakeshore E&W	9 locations						$4,599,600	$190,000	$4,789,600
Branchlines	8 locations						1,151,090	65,000	1,216,090
Total	17 locations						$5,750,690	$255,000	$6,005,690

10.3.2 Pedestrian Overpasses

Pedestrian structures are generally light in construction and have short approaches. Consequently, the cost of raising or replacing this type of structure would not be prohibitive, and would usually be less than track lowering. The raising/replacement and security provisions for the two pedestrian structures affected is estimated to cost $250,000 per structure.

The cost estimates shown in Table 10.6 referring to Pedestrian overpasses assume the following:

- The overpasses will be dismantled and rebuilt, or replaced;
- Public access will be interrupted for the duration of construction.

TABLE 10.6
Cost of Raising/Replacing Pedestrian Overpasses)

Subdivision	Mile	Description	Existing Clearance	Cost
Kingston Weston	326.22 4.27	Danforth Platform Wallace Ave.	6550 6650	$250,000 $250,000
Lakeshore E&W Branchlines	1 Location 1 Location			$250,000 $250,000
Total	2 Locations			$500,000

10.3.3 Signal Structures

To provide adequate electrification clearances for signal structures the following alternatives were considered.

- Raise the existing structure
- Construct a new structure and remove the existing structure once the new one is operational.
- Locally lower the track.

A review of some standard designs for track signal structures (furnished by CN) indicates that adequate vertical clearance currently exists for many of these signal structures. Therefore, although it is anticipated that modifications to track signal structures will not be universally necessary, it was assumed for the purposes of this study that all 110 structures would be affected.

The assumption was made that the additional headroom required at the signal structures will be achieved by relocating the existing units on higher concrete piers built adjacent to the existing foundations. Temporary disruptions of the signals will necessitate the use of flagmen for the duration of the work.

In addition, it has been assumed that protective guards will be provided at each signal structure to preclude the possibility of maintenance personnel on these structures coming in contact with the OCS.

TABLE 10.7
Modifications to Signal Structures

Item	Units	Cantilever Cost	Bridge Cost
Flagging	per structure	$2,000	$2,000
Excavation/Backfill	per structure	500	1,000
Foundations	per structure	2,000	4,000
Extend Cabling	per structure	2,000	2,000
Reposition Structure	per structure	2,500	4,000
Employee Safety Guards	per structure	4,000	6,000
Total		$13,000	$19,000

The cost estimates shown in Table 10.8 referring to Signal Structures assume the following:

- All over-track signal structures will be raised;
- The existing signal structures will be placed on new, higher foundations.

The total cost of raising the 110 overhead signal structures on the GO system is estimated to be under $2 million as outlined in Table 10.8. These costs do not include contingencies or engineering.

TABLE 10.8
Cost of Raising Signal Structures

Location	Count	Description	Unit Cost	Cost
Lakeshore E & W	33	Signal cantilevers	$13,000	$ 429,000
Lakeshore E & W	60	Signal bridges	19,000	1,140,000
Branchlines	6	Signal cantilevers	13,000	78,000
Branchlines	11	Signal bridges	19,000	209,000
Lakeshore E & W	93 Locations			$1,569,000
Branchlines	17 Locations			287,000
Total	110 Locations			$1,856,000

10.3.4 Train Shed - Union Station

12 tracks (six used by GO Transit) at Union Station are covered by the train shed which is approximately 355 metres long by 90 metres wide. Minimum clearance under this roof structure is 5,260 mm which is considerably less than the minimum clearance requirement of 5,500 mm for electrification under passenger operation.

Due to the layout of the track support structure and the passenger concourses below, and the necessity to maintain service during construction, it is not considered practical to lower the track in order to achieve the required clearances. Therefore, clearances must be achieved by raising the roof.

As the additional cost to raise the roof from the minimum requirement of 5,500 mm to the normal requirement of 6,000 mm will not be significant, the latter clearance has been assumed in this study. Alternative means by which the new clearances may be achieved are:

- Demolish roof and replace with similar structure over all tracks;
- Demolish roof and replace with a similar structure over GO tracks;
- Demolish roof and replace with cantilever roof structures over platforms but open over tracks;
- Demolish roof and no replacement;
- Raise the existing roof by jacking.

The existing roof is of riveted structural steel construction with a timber roof deck and concrete smoke ducts above each track. Due to its age and construction, it would not be practical or cost-effective to raise the existing structure. If only the existing GO Transit system is considered, not all platforms would require increased vertical clearance for electrification. However, a new higher structure adjacent to a lower one could increase snow loading considerably on the lower roof. Due to the age of current roof, it is considered prudent to remove it and construct a new roof. This would permit future electrification and expansion over the entire station area.

The partial coverage that would be provided by a cantilever type roof over the platforms would leave some train shed areas exposed to the elements. This is not considered practical or desired at a major commuter facility such as Union Station.

This study therefore assumes that the entire train shed structure from the platforms up will be demolished and replaced with a similar structure.

The cost of roof replacement assumes that a structure similar to the existing will be built. Primary elements of the new shed are a built-up roofing system on a multi-bay system of steel portal frames. Columns would be spaced at about 8 metres in the east-west direction and 18 metres in the north-south direction.

Estimated costs are shown in Table 10.9. The estimate assumes that the design loads will be in accordance with the National Building Code of Canada and that column loads will not be significantly different from present loads. Electrical systems and signage would have to be modified or replaced. Mechanical systems such as elevators and ventilation would also have to be updated or removed. Cost estimates have been included for these items.

Two options were considered for construction of the new structure:

1. Construct new roof above existing and then demolish existing roof;
2. Construct new roof bay-by-bay (i.e. after demolition of existing roof).

Construction of a new roof over the existing would incur higher costs for construction and demolition due to more stringent operational safety constraints and a higher than required vertical clearance. Therefore, this study has assumed that the new shed will be constructed bay-by-bay following the demolitions with no change to the track or platform arrangement.

TABLE 10.9
Cost of Raising Union Station Shed Roof

Item	Units	Quantity	Unit Cost	Cost
Demolition	m^2	32,000	100	$ 3,200,000
Concrete foundations	m^3	200	750	150,000
Structural steel	tonnes	1,450	3,000	4,350,000
Roofing	m^2	32,000	75	2,400,000
Misc. Architectural			1,000,000	1,000,000
Mechanical			2,000,000	2,000,000
Electrical			2,000,000	2,000,000
Total				$15,100,000

The above estimate does not include a contingency or the cost of engineering fees.

10.3.5 Cost Summary

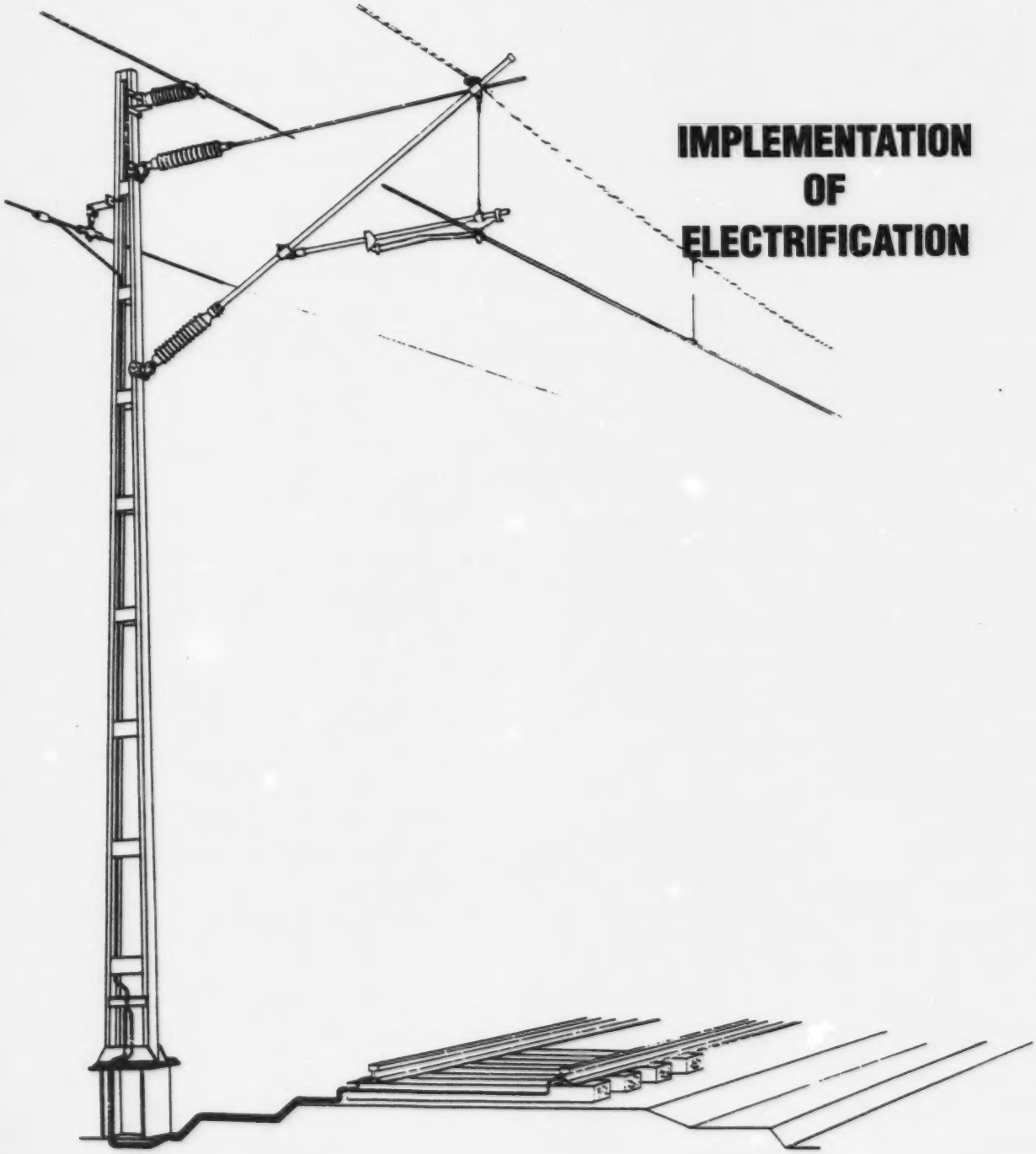
Table 10.9 summarizes the capital cost required to achieve the clearances described in this section.

TABLE 10.10
Electrification Clearances Cost Summary

Item	Line	Basic Cost	25% Contingency	5% Engineering	Total
Track Lowering	Lakeshore	$ 4,789,600	$1,197,400	$ 299,350	$6,286,350
Track Lowering	Branches	1,216,090	304,023	76,006	1,596,118
Pedestrian Overpasses	Lakeshore	250,000	62,500	15,625	[illegible]8,125
Pedestrian Overpasses	Branches	250,000	62,500	15,625	[illegible]8,125
Signal Structures	Lakeshore	1,569,000	392,250	98,063	2,059,313
Signal Structures	Branches	287,000	71,750	17,938	376,688
Station Shed Roof	Lakeshore	15,100,000	3,775,000	943,750	19,818,750
Total		23,461,690	5,865,423	1,466,356	30,793,468

11.

IMPLEMENTATION OF ELECTRIFICATION



CPCS Ltd. in association with Hatch Associates Ltd.

11. IMPLEMENTATION OF ELECTRIFICATION

11.1 ELECTRIFICATION CLEARANCES

11.1.1 Road and Rail Overpasses

Each location where clearances are restricted at a road or rail overpass must be studied to select the best alternative of:

- elimination of the overpass;
- modification or replacement of the overpass;
- raising of the overpass superstructure;
- lowering of the track(s).

Logically, elimination of an overpass is unlikely, and of the three remaining alternatives, track lowering would probably be the least costly. If one of the first three alternatives is selected, then the approval and participation of the agencies responsible for the overpass structure will be needed.

The process of dealing with clearance improvement was described in the preceding section Electrification Clearances.

11.1.2 Implementation of Electrification Clearances

Although a decision on the electrification of GO Transit operations may be several years in the future, the process of providing adequate clearances for electrification should be considered now. The first step in the implementation of electrification clearances is the ratification of new clearance standards by GO Transit and by CN Rail, CP Rail and the TTR. This will involve a further review of standard dimensions for freight and passenger vehicles, electrical clearance standards and OCS hardware characteristics. All railway lines which may be candidates for GO Transit electrification should immediately apply electrification clearance standards to all new over-track construction in the future electrification zone. Existing clearances in the electrification zone should be measured to reconfirm the locations where clearances

are currently sub-standard. In addition, the railways should improve the monitoring and control of clearances to ensure that existing clearances are not diminished in the course of track or structure maintenance.

11.2 SIGNALLING

Implementation of upgraded signalling may precede OCS construction but, as noted above in Section 11.1.3, the adjustment (or replacement) of signal structures should be planned with reference to detailed OCS design. Such coordination also applies to laying of signal cables to structures and track circuits.

11.3 OVERHEAD CONTACT SYSTEM

11.3.1 Installation of OCS

Prior to installation, OCS designers and surveyors will have identified the location of every pole. The relevant sub-assemblies will have been listed, manufactured and stored; or at least ordered in accordance with the installation plan. The foundation design has been designated subject only to occasional on-site adjustment by the Engineer and in accordance with contracted options. Both foundation construction and subsequent pole erection (see Section 9.4.1) can be performed working off the track or from rail vehicles. On an active railway maximum off track work is desirable and must be designated in detail site surveys. However, a work train will be required and require an occupation of side tracks whenever off-track access is impracticable. Portal truss placement will require occupation of a centre track with coordination with all passing trains. All OCS wiring (over track) will require occupation of the respective track, section by section. Some OCS installation, and most maintenance, can be carried out using road-rail bucket trucks. However, converted rail cars are the first choice for new OCS wiring, providing capacity for wire reels, tensioning spools and roof top working platforms.

Agreements as to hours of track occupation, work train operation and crewing are required to be made with each of the Railways at an early stage of project planning. In addition, agreement is needed for work train storage sidings adjacent to temporary

OCS component stock yards. The work train may typically be re-loaded each day at the siding and install OCS during the night. Deliveries into the storage yards will normally be made by road.

A permanent maintenance depot, store, workshop and stock yard, will be needed, holding typically 5 percent of installed components. Rigorous materials management through ordering, manufacture, batching, sub-assembly and distribution to site, can minimize the need for a central construction yard; and also minimize distribution costs and handling.

11.3.2 OCS Maintenance

The cars that make up at least one installation train should be retained by the OCS maintenance department, and normally stored at the OCS maintenance depot. Routine maintenance of OCS sections equivalent to 100 single track kilometres are most effectively performed by a crew of about three men plus supervisor using a specially built road-rail bucket truck, with tools and spare parts. If a mishap leads to section rewiring then extra men would be drafted onto the worktrain.

In Canada, the Consultant has seen very competent OCS maintainers drawn from maintenance-of-way (track) employees. They are already fully aware of track occupancy rules and, with training in basic electrical safety procedures, the OCS work is almost entirely mechanical and/or structural. Certain historical trade union agreements speak for OCS work and this should be clarified early in staff planning.

Annual maintenance cost amounts to about two percent of installed capital cost with direct involvement of about 33 man-hours per kilometre per annum.

11.3.3 Implementation of OCS

The rate of progress of OCS is normally critically determined by the OCS wiring gang occupying sections of track. The gang will typically occupy the track during one shift and install one OCS length of 1.4 km. All other aspects of the work have the flexibility of some or all off-track work. Overall progress can be estimated at 200

single track kilometres per year per work gang, starting one year after completion of detail engineering and specification.

11.4 SUBSTATIONS AND ROLLING STOCK

For detailed engineering and specification allow one year. A reasonable time to complete contracts, construction and commissioning is two years after specification.

The above criteria set normal time frames. For demonstration purposes small quantities of secondhand and/or demonstration equipment are often available together with standard engineering designs.

12.

SIGNALLING AND COMMUNICATIONS

12. SIGNALLING AND COMMUNICATIONS

12.1 INTERACTION BETWEEN ELECTRIC TRACTION AND SIGNALLING

A primary function of railway signalling is to allow the orderly flow of trains over unobstructed tracks. These concepts may involve visual indications from trackside to train drivers or be extended to electronic communication with the train and automatic train control to prevent dangerous operation. In any area of heavy traffic it is necessary that train separation be checked automatically which requires automatic indication of train location. Traditionally this has included detecting electrically whether a train, or any part of it, is on specific lengths of track. Such occupation of a length or section is detected by the "track circuit" for that section and used to signal (to stop) any other train before it enters the next adjacent section. In the most modern systems, the track circuits can monitor the position of a train along a theoretical section and theoretically achieve closer or smoother running of trains. Most modes of train detection pass electric current along the rails of a section to a detector. This current is lost (shunted or shorted out) if any train axles are on the rails in that section.

Since all mainline electric railway schemes pass traction current into the rails, the technical problem arises of ensuring that this current cannot falsely obscure the track circuit train presence detection.

For early dc railways, the track circuit was fed by ac current which could be clearly distinguished by the detector. For early ac railways, the track circuit could be dc or, better, ac of a quite distinct frequency (and not a harmonic of the traction ac).

Complications arose as soon as thyristors were available to control (to chop) dc and alternatively to variously regulate ac; later also creating variable frequency ac.

All the above control processes create low level ac currents (ripple) at harmonic frequencies and/or variable frequency. It is possible to suppress to a large degree (filter) any specific frequency or range of frequencies but at the cost of added,

electrical components. Any such suppression also benefits any possible communications nuisance as discussed in Sections 7.2 and 12.3.

However for signalling purposes it is essential that any proposed electric traction design be coordinated with the actual and planned signalling track circuits design to ensure the most cost effective equipment purchases.

12.2 RE-SIGNALLING GO TRANSIT ROUTES

Existing signalling on GO routes is basically incompatible with railway electrification on either ac or dc traction supply systems. For this reason, this study includes cost estimates for re-signalling. The estimates are based on the existing signalling configuration which, as already noted, becomes a limiting factor if train frequency were to be increased to a few minutes headway.

The necessary investment in re-signalling carries substantial advantages in maintenance and in train operation development which are beyond the scope of this study. Advantages include:

- simplified signalling expansion;
- future introduction of in-train (cab) signalling and safety control.

The latter is considered essential if close headways are required and/or high speed trains are to run through the territory.

A further secondary advantage accrues to electrification in that the signalling supervisory control network is equally applicable to the supervision of electric power circuit breakers and disconnects along the electrified route.

Track circuit apparatus and other signalling components and supervisory controls have already been developed in North America (for one example see Appendix G) compatible with modern electric locomotive designs, stimulated by ongoing North-East Corridor electrification and equipment. These developments form the basis of preliminary estimates for re-signalling of GO Transit routes. As noted above, detail coordination between locomotive and signalling designers is necessary at bidding stage.

Lakeshore (Oshawa-Hamilton) trackage in the electrified area (this exceeds trackage equipped with OCS per section 9.6.1), is estimated at 490 km, exclusive of sidings.

Basic upgrading for electrification

	Cost per single track km
Track impedance bonds installed	$12,500
Logic processor and output drivers installed	$12,500
	$25,000

or $12.25 million for 490 km.

Most modern electrification schemes have involved the substantial replacement and/or rebuilding of signalling equipment. In addition to the benefit of complete upgrading, this allows more comprehensive testing of new equipment prior to operational changeover from old system to new system and avoids the serious operational disruption if existing equipment is temporarily shut down for reconnection and testing. It also permits optimum siting of signals in relation to OCS.

Current estimates on the above basis expressed as single track km range from $150,000 (North East Corridor) to $260,000 (Southern California) or $73.5 million to $127 million for the Lakeshore route.

The Consultant proposes to carry $50 million into the costing of this study (Section 13.2) as a cost borne by electrification.

The cab signalling option, including automatic "speed enforcement" according to signal status ahead, costs about $45,000 per driving cab - installed.

The Consultant understands that re-signalling of the Union Station area (Toronto Terminals Railway) is currently being planned/designed. It is strongly recommended that any new installations be electrification compatible or at least suitable for upgrading by modular additions.

12.3 ELECTRIC TRACTION AND RAILWAY COMMUNICATION FACILITIES

As stated previously, electrification as proposed would cause troublesome interference to open wire pole line communications and also to unshielded cables in proximity to the railway right-of-way. However, two of the more modern modes of communication are virtually unaffected by electrification.

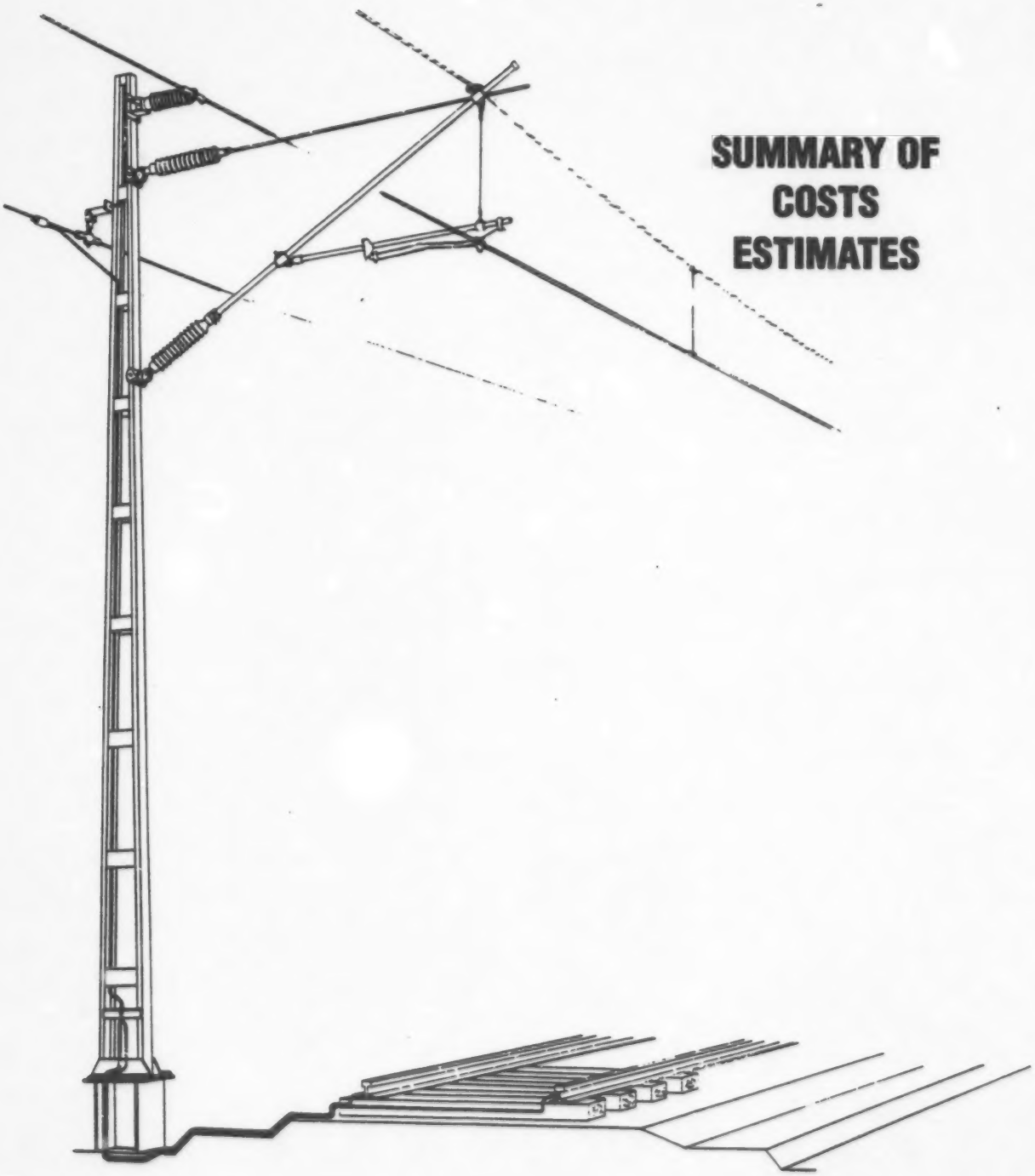
Mobile train radio at VHF and UHF frequencies has been found to be unimpaired.

Fibre optic cable is inherently immune to interference and is a technology already introduced by CN onto the Lakeshore East line and in sections of the Lakeshore West line. One impetus for these installations has been to suppress interference caused by utility power lines adjacent to the railway right-of-way.

12.4 ELECTROMAGNETIC INTERFERENCE

Further to Section 7.2.3, it is anticipated that very little, if any, new electromagnetic interference will be noticed outside the railway right-of-way by users of modern electronic devices lawfully connected and installed. However, to deal with any bonafide claims from users of affected (probably older style) equipment, a contingency of $5 million is recommended for site specific remedies. It is unlikely that any such problems will be identified before electric trains actually start to run in the area.

13.



SUMMARY OF COSTS ESTIMATES

13. SUMMARY OF COST ESTIMATES

13.1 OPERATING SCENARIOS

Four scenarios have been assembled to evaluate the financial impacts of electric versus diesel operations for the passenger traffic needs assumed by the terms of reference for this study. The scenarios are intended to establish benchmarks for economic analysis in Section 14. They do not necessarily represent the optimum configuration for passenger service and revenue.

Scenario 1

All trains will be diesel locomotive powered with bi-level coaches. The Lakeshore service will be every 10 minutes during the peak period and every 30 minutes offpeak. The Saturday, Sunday and holiday service remains unchanged with hourly intervals. All of the trains will comprise 10 bi-level coaches and will operate between Hamilton and Oshawa.

The Branchline service will be increased to every 20 minutes during the peak period and hourly offpeak. The Branchline service will be weekday only. All of the additional trains placed into the service will haul 10 bi-level coaches. The Branchline service will terminate at Milton, Guelph, Barrie, Richmond Hill and Stouffville.

Additional diesel locomotives, bi-level coaches and workshop/storage facilities will be required.

The rate of diesel fuel consumption (expressed in litres per train kilometre) will be assumed to be the present average over all routes: 9.05 litres per train kilometre for costing purposes.

Scenario 2

The service intervals for the Lakeshore and Branchline train services are as in Scenario 1 above.

Under this scenario the Lakeshore service will be handled with electric locomotives while the Branchline service will remain diesel hauled.

For the Lakeshore service the journey time has been reduced as per the ALP44 locomotive simulation summarized in Table 8.1. The reduced journey time has been reflected into a reduced fleet size as per Section 8.7.2. The energy consumption level has been calculated based upon values contained in Table 8.1 and Figure 8.3. This results in an energy consumption level of 43.24 kWh per train kilometre. As noted in Section 8.6.1, the actual rate of energy (fuel) consumption rises sharply with higher accelerations for reduced journey times. If an electric locomotive or equivalent EMU train were operated at exactly the same speed profile as attained by the diesel, then the simulated rate of energy consumption and journey time would be equal to that of the diesel.

The description of the Branchline diesel service in Scenario 1 remains the same.

Overall, electric locomotives and bi-level coaches are required for this scenario. There will be a small surplus of diesel locomotives. The majority of the diesels will be needed to provide the expanded service on the Branchlines.

The costs (if not the details) of any facilities are assumed to be the same as Scenario 1.

For Scenarios 2, 3 and 4 it will be assumed that additional rolling stock requirements will be built-up based upon the present fleets of diesel locomotives and bi-level coaches. The values will not be based upon the analysis or needs described in Scenario 1. For the purposes of this analysis, diesel locomotives will not be purchased to operate the train service defined by Scenario 1 and subsequently be declared surplus within one half of their useful lives.

Scenario 3

The service intervals for the Lakeshore and Branchline train services are as in Scenarios 1 and 2.

Under this scenario both the Lakeshore and Branchline train services will be handled with electric locomotives.

The description for the Lakeshore will remain as outlined in Scenario 2.

For the Branchlines, a rate of energy consumption has been adopted from Table 8.2A: 33 kWh per train kilometre which is very close to the diesel system average used in Scenario 1 (9.05 litres equivalent to 32.2 kWh - Section 8.7.1) but yields some reduction in journey time on the branchlines. This reduction, however, is deemed insufficient to reduce the peak period equipment needs and the number of train sets on the branches remains the same as in Scenario 2.

Overall, electric locomotives and bi-levels will be required. All of the present fleet of diesel locomotives will be considered surplus.

The costs of workshop/storage facilities is assumed constant from Scenario 1.

Scenario 4

The service intervals on the Lakeshore and Branchline train services are as in Scenarios 1, 2 and 3. Under this scenario the Lakeshore service will be hauled with electric locomotives as in Scenarios 2 and 3 while the Branchlines will be serviced with EMU sets.

For the Branchlines, the train consist is assumed to be 10 car sets during the peak period and 2 car sets during the offpeak. The same peak period energy consumption and journey times as in Scenario 3 are assumed but the offpeak period energy consumption is reduced to one-fifth of the peak. This scenario has been developed to investigate the economics of EMU in the absence of passenger demand/revenue components in this study.

Overall, electric locomotives, EMU power cars and bi-level coaches will be required. The fleet of diesel locomotives are deemed to be surplus.

The costs of workshop/storage facilities are assumed to be constant from Scenario 1.

Table 13.1 presents the four scenarios in summary form.

TABLE 13.1
Scenario Summary

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Lakeshore Line				
- Diesel Loco (D)				
- Electric Loco (E)	D	E	E	E
Branchlines				
- Diesel Loco (D)				
- Electric Loco (E)				
- EMU (M)	D	D	E	M
Peak Service				
- Lakeshore	10 min.	10 min.	10 min.	10 min.
- Branchlines	20 min.	20 min.	20 min.	20 min.
Off-Peak Service				
- Lakeshore	30 min.	30 min.	30 min.	30 min.
- Branchlines	60 min.	60 min.	60 min.	60 min.
Peak Train Consist				
- Lakeshore	10 cars	10 cars	10 cars	10 cars
- Branchlines	10 cars	10 cars	10 cars	10 cars
Off-Peak Train Consist				
- Lakeshore	10 cars	10 cars	10 cars	10 cars
- Branchlines	10 cars	10 cars	10 cars	2 cars

13.2 CAPITAL COST ESTIMATES

13.2.1 Overhead Contact System

As stated earlier in Section 9.4.1, the OCS can be constructed with close to 100% Canadian content with strong competition in most of the hardware manufacturing and installation tasks. However, today's pricing based on real Canadian production within the decade is probably depressed by the general business recession. This pricing was included in the low/high spread Table 9.2 of Section 9.6.1. An average price was carried forward into Table 9.3 and the final result is shown in Table 13.2 item 1.

13.2.2 Power Substations

Costs are carried forward from Table 9.4 of Section 9.6.2. The Main Substation costs applies equally to the Lakeshore or to the full network electrification. The Feeder Substations are route specific. 45% of the Auto Transformer and Paralleling costs relate to the Lakeshore line.

Costs are entered in Table 13.2 item 2.

13.2.3 Rolling Stock

Locomotive and passenger car needs are estimated from the incremental equipment needed to provide the extra service (longer routes and more frequent trains) on which this study is based. Provision has been made for shop to end point equipment moves (or vice versa) but overall availability is assumed to be 90% or better for all options.

EMU needs are estimated as ten car trains for Branchlines peak service but with a resulting seat reduction from 1620 to 1420 seats per train.

Unit costs are tabulated in Table 6.1 of Section 6.5 and are carried forward into Section 14 based upon quantities entered in Table 13.2 item 7.

13.2.4 Civil Engineering

The costs of civil works relating to electrification clearances are taken from Table 10.10 of Section 10.3.5 and entered in Table 13.2 item 3.

13.2.5 Signalling/Telecommunications

As described in Section 12.2, a signals cost of $50 million is assigned to the Lakeshore line electrification. A contingency of $5 million is provided for EMI mitigation as described in Section 12.4.

The projected cost of $50 million plus $5 million EMI mitigation applied to the Branchlines is provisional. The "signalling" system to be adopted will be influenced by the Railway's plans for other than commuter rail traffic. As noted in Section 12, upgrading of the signalling equipment will provide direct benefits to overall railway operations and maintenance.

These costs are entered in Table 13.2 item 4.

13.2.6 OCS Maintenance Equipment

As noted in Section 11.2 some of the OCS construction equipment should remain on railway property. Particularly one or more wiring trains. These are costed into construction. However, it is prudent to commission some new speciality road/rail OCS maintenance vehicles at the start of regular operations. Three such new vehicles are proposed for the Lakeshore line and three more for the Branchlines at a unit cost of $500,000. These are entered in Table 13.2 as item 5.

13.2.7 Facilities

Electric/Mechanical Shops

Based on incremental equipment needs a cost is entered in each scenario representing a new shop and up to 16 km of trackage. The shop is nominally the basic size of Willowbrook. Actual equipment and layout would depend on rolling stock mix adopted. However, optimum length will accommodate ten car train sets with up to four full length inspection tracks if EMU's dominate (Scenario 4).

Building and equipment	$28 million
Trackage	$10 million

OCS Maintenance Shops

A provision of $2 million is made for an OCS maintenance shop and tools to assemble and overhaul speciality OCS components such as section isolators, disconnects and also wiring equipment and tools.

The above facilities estimates are carried forward into Table 13.2 item 6.

No provision has been made for the cost of land acquisition for these facilities since the cost of the land will be greatly dependent upon the geographic location of the actual sites selected.

13.3 OPERATING COST ESTIMATES

13.3.1 Energy

Energy consumption for each scenario is derived from estimated train kilometres per year multiplied by the consumption per kilometre apportioned to the Lakeshore line and Branchlines respectively for each scenario in Section 13.1 above.

The energy consumption is entered in Table 13.2 item 10 as Megalitres of diesel fuel for diesel locomotives or Gigawatt-hours of electrical energy for electric trains.

Section 8.8.1 refers to a possible 10% saving of electrical energy through recovery of braking energy. The significance of this is tested in the economic analysis of Section 14.

13.3.2 Electric Power Bureau

This office would be manned at all times to monitor substation and OCS power, circuit breakers and disconnects. Monitoring and control is achieved through computer terminals and communication interfaces (SCADA) included in "Substation" costs. Little office space would be required and it would normally be an office module adjacent to the regional train dispatching facility. Regular duties would generally comprise isolating sections of OCS and issuing electrical protection orders to OCS maintenance crews. An estimated operating cost covering continuous 24 hour manning plus supervision is entered into Table 13.2 item 9.

13.3.3 Crew Wages

Crew wages (Table 13.2 item 8) are assumed to be invariant between the four scenarios since the wage payments are linked to trip (i.e. timetable) assignments. Therefore, crewing cost will not be affected by journey time reductions estimated under electrified service.

13.4 MAINTENANCE COST ESTIMATES

13.4.1 OCS Maintenance

An annual maintenance cost equal to 2% of installed capital cost is entered in Table 13.2 line 11. This is considered to be a reliable estimate where capital cost contains a high content of local labour and materials.

13.4.2 Power Substation Maintenance

An annual maintenance cost allowance equal to 2% of the installed capital cost has been entered in Table 13.2 line 12.

13.4.3 Diesel Locomotive Maintenance

1990/91 GO Transit equipment maintenance costs for locomotives have been taken as a base. Workshops Supervision and Overhead have been apportioned in the ratio of locomotive to coach direct costs. Incremental costs/savings are entered in Table 13.2 item 15.

13.4.4 Electric Locomotive Maintenance

Electric locomotive maintenance costs (Section 6.6 refers) have been entered into Table 13.2 item 13 using the upper limit estimate of Table 6.1. This is 66% of diesel maintenance per unit covering a full spectrum of work from daily (trip) inspections through to heavy overhauls.

13.4.5 Bi-Level Coach Maintenance

1990/91 GO Transit equipment maintenance costs for coaches have been taken as a base. Workshops Supervision and Overhaul have been apportioned in the ratio of coach to locomotive direct costs. Incremental costs are entered in Table 13.2 item 16.

13.4.6 EMU Power Car Maintenance

Power Car Maintenance includes the full costs of trailer coach (Bi-level) maintenance, per coach, as derived in Section 13.4.5 above. This includes both interior and basic running gear maintenance. An equal amount has been estimated per unit for maintenance of X10 type traction power and control equipment. Power car costs are entered in Table 13.2 item 14 and the paired trailer bi-level is included in item 16 of Scenario 4.

13.4.7 Signals-Telecommunications Maintenance

This element of maintenance costs, listed as Table 13.2 item 17, is assumed to be invariant between the four scenarios. Some increased signalling on the branchlines with electrification will be offset by savings from Lakeshore upgrading.

13.4.8 Track Maintenance

This element of maintenance costs, listed as Table 13.2 item 18, is assumed to be invariant between the four scenarios from being chiefly related to time and train mileage.

13.4.9 Seat Kilometres

For each scenario, the estimated total annual seat kilometres were developed for application in Section 14 - Economic Analysis.

These seat kilometres are shown in Table 13.2 item 19 separated between the Lakeshore line and the Branchlines.

13.5 MARKET CONDITIONS

In comparing today's electrification costing in relation to both past experience and future projections several anomalies appear. These anomalies are created in today's marketplace but may not be sustained.

1) **Diesel Locomotives**. Some degree of mass-production in North America plus a business recession makes today's pricing look undervalued some 20%.

2) **Electric Locomotives**. There is no significant production in North America at this time. Pricing of modern designs is currently set at European levels clearly intended to achieve rapid recovery of development costs. As noted earlier, designs have advanced significantly during the past two decades. On a sustained production basis electric locomotives are overpriced by some 50%. (Today's price is 150% mass production price.)

3) **Fuel and Energy Costs**. Reference to electrification projections made over the last decade shows that the regulated costs of electrical energy have risen in step with the overall rate of inflation

However, predicted dramatic rises in fuel oil price did not occur during the decade. After some rise the price dropped back and today's price is roughly the same as ten years ago.

Thus, with due consideration of load factor as noted earlier, today's railway electricity cost is commeasurate with diesel fuel cost whereas at other times it has been demonstrated to be 50% or less of diesel fuel and a very significant component of electrification benefit.

4) **Overhead Contact System.** As stated earlier, the OCS can be constructed with close to 100% Canadian content with strong competition in most of the hardware manufacturing and installation tasks. However, today's pricing based on real Canadian production within the decade is probably depressed by the general business recession. The cost spread used in this report reflects both detail design uncertainties and conditions in the marketplace.

13.6 OTHER REGIONAL BENEFITS OF GO ELECTRIFICATION

Investment in electrification of the GO Transit rail system as defined within the terms of this study would confer very substantial additional benefits to the Region, all outside the scope of this study:

1) Local manufacture and installation.

a)	Locomotives	up to 70%
b)	Overhead Contact System	up to 100%
c)	Substations and Control	up to 100%
d)	Signalling	up to 50%
e)	Clearances and Civil Works	up to 100%

2) Opportunity to over-build railway trackage.
3) Opportunity to increase GO Transit peak capacity.
4) Opportunity to provide high quality low cost off-peak rail service.
5) Through running of high speed train on Lakeshore route.
6) Electric haulage of heavy freight trains through Lakeshore route.

13.7 SUMMARY

The following Table 13.2 summaries the costs and quantities for the items outlined in Sections 13.2, 13.3 and 13.4.

The costs and quantities in Table 13.2 will be carried forward into Section 14 - Economic Analysis.

TABLE 13.2

	Scenario #1	Scenario #2	Scenario #3	Scenario #4
Estimated Capital Costs				
1. OCS	N/A	$76,300,000	$194,900,000	$194,900,000
2. Substations (SCADA, Power Bureau)	N/A	34,900,000	71,100,000	71,100,000
3. Civil Works	N/A	28,500,000	30,800,000	30,800,000
4. Signals/Comms				
- Upgrading	N/A	50,000,000	100,000,000	100,000,000
- EMI Mitigation	N/A	5,000,000	10,000,000	10,000,000
5. OCS Mtce. Eqpt.	N/A	1,500,000	3,000,000	3,000,000
6. Facilities				
- Elect/Mech Shop	$38,000,000	38,000,000	38,000,000	38,000,000
- OCS Mtce. Shop	N/A	2,000,000	2,000,000	2,000,000
Estimated Rolling Stock Requirements				
7. Rolling Stock				
- Electric Locos	N/A	32	59	32
- EMU Power Cars	N/A	N/A	N/A	138
- Diesel Locos	24	(12)	(42)	(42)
- Bi-levels	297	204	204	123
Estimated Operating Costs				
8. Crew Wages	-	-	-	-
9. Power Bureau	N/A	$500,000	$500,000	$500,000
Estimated Energy Needs				
10. Energy				
- Diesel Fuel				
Lakeshore	36.8 Ml.			
Branches	43.3 Ml.	43.3 Ml.		
- Electricity				
Lakeshore	N/A	176 GWh	176 GWh	176 GWh
Branches	N/A		158 GWh	95 GWh
*GWh = Million kWh				
Estimated Maintenance Costs				
11. OCS Maintenance	N/A	$1,526,000	$3,898,000	$3,898,000
12. Substation Mtce.	N/A	698,000	1,422,000	1,422,000
13. Electric Loco. Mtce.	N/A	3,800,000	6,900,000	3,800,000
14. EMU Maintenance	N/A	N/A	N/A	10,400,000
15. Diesel Maintenance	$4,300,000	(2,100,000)	(7,500,000)	(7,500,000)
16. Bi-level Mtce.	10,800,000	7,400,000	7,400,000	4,500,000
17. Signals/Comm.	-	-	-	-
18. Track Maintenance	-	-	-	-
Estimated Annual Seat Kilometres (millions)				
19. Lakeshore	6,584	6,584	6,584	6,584
Branchlines	7,740	7,740	7,740	4,070

14.

ECONOMIC ANALYSIS

CPCS Ltd. in association with Hatch Associates Ltd.

14. ECONOMIC ANALYSIS

This section presents unit cost estimates used to evaluate the costs of dieselization and electrification of the GO Transit system during the study horizon. The cost estimates are based on four operating scenarios as described in Section 13. Under each scenario, operating costs at current and potential service levels (measured in seat kilometres) were combined with infrastructure construction costs, rolling stock and equipment acquisition and replacement costs and maintenance costs to generate a stream of expenditures in each year of the 30 year planning horizon. The present value of the stream of costs for each scenario was calculated at a discount rate of 3.75%. This value is converted into a cost per seat-kilometre (life cycle average cost per seat-kilometre) for each scenario. This permits ready comparison between scenarios on a unit basis. In addition, sensitivity analyses were performed on each scenario to isolate the impact of changes of certain key variables on the results.

14.1 DIESELIZATION AND ELECTRIFICATION COSTS

Costs were developed for the Lakeshore Line and the Branchlines separately, and then were combined for each of the scenarios described in Section 13.1. Table 14.1 is a cost summary which presents total capital expenditures required over the life of the project along with annual operating and maintenance costs at full service levels, for each scenario. Tables 14.2 through 14.5 show the stream of costs, by year, associated with each scenario during the planning horizon. All costs have been expressed in constant Canadian dollars as of January 1, 1992. Unit costs for capital expenditures and operating and maintenance costs were developed as described in Section 13.

The capital investment in locomotives and rolling stock is the cost of additional equipment required to handle full service levels and replacement of these as well as replacement of the existing fleet where required. A salvage value of 10% of the original cost of locomotives and rolling stock was calculated for that equipment that had reached the end of its useful life at the end of the project. Residual values based on straight line depreciation were calculated for equipment that had a remaining useful life at the end of the project. The useful economic life of a diesel locomotive

TABLE 14.1

Summary of Economic Costs Comparing Dieselization and Electrification at Full Service Levels ($ millions)

COST ITEM	SCENARIOS			
	1	2	3	4
CAPITAL COSTS				
OCS	0.0	76.3	194.9	194.9
Substations (SCADA/Power Bureau)	0.0	34.9	71.1	71.1
Rolling Stock:				
Electric Locos	0.0	192.0	354.0	192.0
EMU Power Cars	0.0	0.0	0.0	345.0
Diesels	225.0	75.0	0.0	0.0
Bi-Levels	445.5	306.0	306.0	184.5
TOTAL ROLLING STOCK	670.5	573.0	660.0	721.5
Civil Works	0.0	28.5	30.8	30.8
Signalling/Communications				
Upgrade Systems	0.0	50.0	100.0	100.0
EMI Mitigation	0.0	5.0	10.0	10.0
TOTAL SIGNALS & COMMUNICATIONS	0.0	55.0	110.0	110.0
OCS Maintenance Equipment	0.0	1.5	3.0	3.0
Facilities (Bldgs.)				
Electro/mech. Shop (Conv/Acquis.)	38.0	38.0	38.0	38.0
OCS Mtce. Shop	0.0	2.0	2.0	2.0
TOTAL FACILITIES	38.0	40.0	40.0	40.0
TOTAL CAPITAL COSTS	708.5	809.2	1,109.8	1,171.3
OPERATING COSTS				
Diesel				
Lakeshore	7.6	0.0	0.0	0.0
Branches	9.0	9.0	0.0	0.0
TOTAL DIESEL	16.6	9.0	0.0	0.0

COST ITEM	SCENARIOS			
	1	2	3	4
Electric				
Lakeshore	0.0	11.6	11.6	11.6
Branches	0.0	0.0	10.4	6.3
TOTAL ELECTRIC	0.00	11.6	22.1	17.9
TOTAL ENERGY	16.6	20.6	22.1	17.9
Crews	-	-	-	-
Power Bureau Operation	0.0	0.5	0.5	0.5
TOTAL OPERATING COSTS	16.6	21.1	22.6	18.4
MAINTENANCE COSTS				
OCS Maintenance	0.0	1.5	3.9	3.9
Substation Maintenance	0.0	0.7	1.4	1.4
Elec. Rolling Stock Mtce.	0.0	3.8	6.9	3.8
Diesel Mtce.	11.8	5.4	0.0	0.0
Signals/Comms. Mtce.	-	-	-	-
Track Maintenance	-	-	-	-
Bi-Levels Mtce.	22.8	19.4	19.4	16.5
EMU Maintenance	0.0	0.0	0.0	10.4
TOTAL MAINTENANCE COSTS	34.6	30.8	31.6	36.0
Present Value @ 3.75% ($ millions)	1,046.3	1,148.0	1,347.4	1,383.9
Avg. Life Cycle Cost ($/seat kilometre)	0.0062	0.0068	0.0080	0.0082

Scenarios Legend:
- #1 - Diesel
- #2 - Electrified Lakeshore, diesel branchlines
- #3 - All lines electrified
- #4 - Lakeshore electrified, EMU on branchlines

TABLE 14.2
SCENARIO 1
Economic Cost of Reaching Full Service Using Diesel Locomotives Throughout the System
(All figures in millions unless otherwise stated)

YEAR	TRAFFIC	OPERATING AND MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:						Rolling Stock											
	Seat Kms.	Diesel	Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Mtce. Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap. Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064											0.0	24.0
2	3736	4.5			19.5	24.0	0.0064											0.0	24.0
3	3736	4.5			19.5	24.0	0.0064											0.0	24.0
4	3736	4.5			19.5	24.0	0.0064											0.0	24.0
5	3736	4.5			19.5	24.0	0.0064											0.0	24.0
6	3736	4.5			19.5	24.0	0.0064											0.0	24.0
7	3736	4.5			19.5	24.0	0.0064											0.0	24.0
8	3736	4.5			19.5	24.0	0.0064										12.7	12.7	36.7
9	3736	4.5			19.5	24.0	0.0064										12.7	12.7	36.7
10	3736	4.5			19.5	24.0	0.0064	60.0			445.5						12.7	518.2	542.2
11	14324	16.6			34.6	51.2	0.0036											0.0	51.2
12	14324	16.6			34.6	51.2	0.0036											0.0	51.2
13	14324	16.6			34.6	51.2	0.0036											0.0	51.2
14	14324	16.6			34.6	51.2	0.0036											0.0	51.2
15	14324	16.6			34.6	51.2	0.0036	94.5										94.5	145.7
16	14324	16.6			34.6	51.2	0.0036											0.0	51.2
17	14324	16.6			34.6	51.2	0.0036											0.0	51.2
18	14324	16.6			34.6	51.2	0.0036											0.0	51.2
19	14324	16.6			34.6	51.2	0.0036											0.0	51.2
20	14324	16.6			34.6	51.2	0.0036											0.0	51.2
21	14324	16.6			34.6	51.2	0.0036											0.0	51.2
22	14324	16.6			34.6	51.2	0.0036											0.0	51.2
23	14324	16.6			34.6	51.2	0.0036											0.0	51.2
24	14324	16.6			34.6	51.2	0.0036											0.0	51.2
25	14324	16.6			34.6	51.2	0.0036	54.0										54.0	105.2
26	14324	16.6			34.6	51.2	0.0036											0.0	51.2
27	14324	16.6			34.6	51.2	0.0036											0.0	51.2
28	14324	16.6			34.6	51.2	0.0036											0.0	51.2
29	14324	16.6			34.6	51.2	0.0036											0.0	51.2
30	14324	16.6	—	—	34.6	51.2	0.0036	(55.1)	—	—	(232.5)	—	—	—	—	—	(3.8)	(291.3)	(240.1)
TOTAL	323840	376.6			867.7	1264.3	0.1356	153.4			213.0						34.2	400.7	1665.0

PV Total Costs @ 3.75% $1,046.3 (millions)

Life Cycle Average Cost 0.0062 ($/seat km)

TABLE 14.3
SCENARIO 2
Economic Cost of Electrifying the Lakeshore Line
(All figures in millions unless otherwise stated)

YEAR	TRAFFIC	OPERATING AND MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:						Rolling Stock											
	Seat Kms.	Diesel	Electric	Power Bureau	Mtce.	Total Ope & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Mtce. Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap. Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9
9	3736	4.5			19.5	24.0	0.0064						38.2		17.5	27.5	13.3	96.4	120.5
10	3736	4.5			19.5	24.0	0.0064	(12.6)	192.0		306.0		38.2	1.5	17.5	27.5	13.3	563.3	607.3
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										67.5	119.4
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(78.8)	—	(175.2)	—	(7.6)	—	(3.5)	—	(4.0)	(276.6)	(224.7)
TOTAL	323840	225.0	232.6	10.0	811.7	1278.8	0.1369	47.4	113.2		130.8	28.5	68.7	1.5	31.4	55.0	36.0	512.4	1791.3

PV Total Costs @ 3.75% $1,148.0 (millions)

Life Cycle Average Cost 0.0066 ($/seat km)

TABLE 14.4
SCENARIO 3
Economic Cost of Using Electric Locomotives over the Entire System
(All figures in millions unless otherwise stated)

YEAR	TRAFFIC	OPERATING AND MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:						Rolling Stock											
	Seat Kms.	Diesel	Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Mtce. Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap. Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	13.3	201.3	225.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	354.0		306.0		97.5	3.0	35.6	55.0	13.3	820.1	844.1
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038	—	(145.3)	—	(175.2)	—	(19.5)	—	(7.1)	—	(4.0)	(351.1)	(296.9)
TOTAL	323840	45.0	441.5	10.0	827.7	1324.7	0.1401	(44.3)	208.7		130.8	30.8	175.4	3.0	64.0	110.0	36.0	714.5	2039.2

PV Total Costs @ 3.75% **$1,347.4 (millions)** **Life Cycle Average Cost** **0.0080 ($/seat km)**

TABLE 14.5
SCENARIO 4
Economic Cost of Using Electric Locomotives on the Lakeshore Line and EMU Cars on the Branch Lines
(All figures in millions unless otherwise stated)

YEAR	TRAFFIC	OPERATING AND MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:						Rolling Stock											
	Seat Kms.	Diesel	Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Mtce. Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap. Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	13.3	201.3	225.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	192.0	345.0	184.5		97.5	3.0	35.6	55.0	13.3	881.6	905.6
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038	—	(78.8)	(141.6)	(125.4)	—	(19.5)	—	(7.1)	—	(4.0)	(376.3)	(321.9)
TOTAL	323840	45.0	358.2	10.0	915.7	1329.4	0.1404	(44.3)	113.2	203.4	59.1	30.8	175.4	3.0	64.0	110.0	36.0	750.7	2080.1

PV Total Costs @ 3.75% **$1,363.9 (millions)** **Life Cycle Average Cost** **0.0082 ($/seat km)**

was estimated to be 15 years. That of electric locomotives, bi-level cars and EMU cars was estimated to be 30 years. A salvage value of 10% of original cost was allowed for infrastructure at the end of the project.

Operating costs were based on information provided by GO Transit during the data collection phase of this study. The cost of diesel fuel is the current price paid by GO Transit and is $0.2862 per litre. Provincial sales tax of $0.0395/l and excise tax of $0.04/l have been removed to reflect the economic cost of fuel and the net cost of $0.2067 has been used in all calculations. The cost of electricity was provided by Ontario Hydro and is $0.06609 per KWh.

An underlying assumption of the cost analysis is that full service operation for all scenarios does not begin until year 11 of the study period. Construction of electrification infrastructure and purchase of electric locomotives, rolling stock maintenance equipment for scenarios 2, 3 and 4 takes place in years 8, 9 and 10. In order to make the scenarios strictly comparable, it would be necessary to operate the system in scenarios 1, 2, 3 and 4 using diesel locomotives only until full service under electrification, begins in year 11. As a convenience for analysis, traffic and capital, operating and maintenance costs remain at current levels under all scenarios until year 11, when full service begins. Clearly in a real life situation, there would be an incremental increase in these elements during the first 10 years of the analysis period leading to full service in year 11. In terms of acquisition of diesel locomotives and rolling stock, this would most likely take the form of purchase for scenario 1 and leasing for scenarios 2, 3 and 4.

Table 14.6 summarizes and compares the total cost for each scenario. It can be seen that scenario 1, complete dieselization, has the lowest total cost. This is due mainly to lower infrastructure costs compared to all other scenarios.

Because the amount and timing of expenditures is different for each of the scenarios presented here, total costs must be compared on a present value basis for such comparisons to be meaningful. Table 14.7 summarizes the present value of costs at a 3.75% discount rate and compares the life cycle average cost per seat-kilometre.

TABLE 14.6
SUMMARY OF TOTAL COSTS
($ Millions)

Scenario	Operating Cost	Capital Cost	Total Cost	Capital Cost as % of Total
1	1,264.3	400.7	1,665.0	24.07%
2	1,278.8	512.4	1,791.2	28.61%
3	1,324.7	714.5	2,039.2	35.04%
4	1,329.4	750.7	2,080.1	36.09%

TABLE 4.7
TOTAL AND AVERAGE COST OVER 30 YEARS
($ Millions)

Scenario	Present value @ 3.75%	Increase over Scenario One	Life Cycle Average Cost Dollars/Seat Km.
1	1,046.3		0.0062
2	1,148.0	101.7	0.0068
3	1,347.4	301.1	0.0080
4	1,383.9	337.6	0.0082

The life cycle average cost provides a convenient representation in a single number of a stream of costs which vary over time. This is in effect an average cost which takes into account the effect of discounting of future values over the time horizon chosen to represent the useful life of the project. Two methods may be used to calculate the life cycle average cost. The most obvious calculation is an iterative one. Referring to Table 14.2, we select an arbitrary value for the life cycle average cost as a "test" number, such as 1 dollar per seat kilometre. When multiplied by the annual seat kilometres (column 1) it will provide an estimate of annual cost, similar to the Grand Total column. The present value of that stream will be found to be $168,429.1 million. This is 160.9 times greater than the desired value, that is the present value of total costs, which is $1046.3 million. Therefore, we know that the initial estimate of $1.00 per seat kilometre life cycle average cost was too high and

should be reduced by a factor of 1/160.9. This will yield .0062 dollar per seat kilometre.

A more convenient direct calculation is to divide the present value of annual cost by the present value of the stream of traffic. The latter can be thought of as the present value of costs of that traffic stream at a cost of $1.00 per seat kilometre. In this case, that value is $168,429.1 million. Dividing this number into the present value of total costs of $1046.3 million gives a value of .0062 dollar per seat kilometre.

On a present value basis as well as in terms of life-cycle average cost, the ranking of the cost of each scenario remains the same as on a total cost basis, with scenario 1 being the cheapest option. Scenarios 3 and 4 are the most expensive options because, as mentioned above, of the high capital investment required in electrification infrastructure.

Recall from the presentation above that federal excise tax and provincial tax on diesel fuel of about $0.018/litre or 27% are excluded from those costs because they are financial in nature, not economic.

14.2 SENSITIVITY ANALYSIS

Sensitivity analyses were performed on each scenario to isolate the impact of changes in certain key variables on the results. Table 14.8 summarizes and compares the present value of total costs for the four basic scenarios discussed above with the scenarios in which key variables have been changed. Table 14.9 summarizes and compares cost per seat kilometre (life cycle average cost) in the same way.

Although sensitivity analyses were performed for increases in the price of diesel fuel, they were not undertaken for the price of electric energy. The price of diesel fuel can be extremely volatile in response to unforeseen and uncontrollable political events which dictate how market forces react. The determinants of the price of electric energy are not volatile and therefore the price of electric energy would maintain its relative position vis-a-vis other cost items within the analysis.

With respect to increases in the price of diesel fuel, the peak price recorded in October 1990 was used. This was $0.3059 per litre (Source: DRI McGraw Hill). For changes in traffic levels, the number of seat kilometres was increased and decreased by 20% with an appropriate increase or decrease in relevant costs. Signalling costs were tested at 0 cost, under the assumption that the railways would benefit from these improvements and would pay all these costs; and at double costs, under the assumption that GO Transit would bear all the costs. The basic assumption used was that the cost of improvements to the signalling system would be borne equally by the railways and GO. The cost of OCS infrastructure was varied +/-20%. A decrease of 30% in the price of electric locomotives was tested.

Table 14.8 shows that while in present value terms the absolute costs increased or decreased correspondingly, the rankings of the scenarios did not change compared to the base case.

TABLE 14.8
SUMMARY
Present Value of Total Costs ($ million)
(Sensitivity Analysis)

Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Basic	1,046.3	1,148.0	1,347.4	1,383.9
Diesel Fuel Increase	1,140.7	1,207.3	1,365.3	1,401.8
Traffic Increase	1,286.5	1,374.0	1,579.9	1,602.0
Traffic Decrease	805.4	921.3	1,114.2	1,165.0
Signalling Costs - 0	n/a	1,112.7	1,276.9	1,313.4
Signalling Costs - Double	n/a	1,183.2	1,417.9	1,454.4
OCS Costs: +20%	n/a	1,158.3	1,373.6	1,410.1
OCS Costs: -20%	n/a	1,137.7	1,321.2	1,357.7
Electric Loco Price Decrease	n/a	1,116.0	1,288.4	1,351.8

TABLE 14.9
SUMMARY
Cost per Seat Kilometre ($)
(Sensitivity Analysis)

Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Basic	0.0062	0.0068	0.0080	0.0082
Diesel Fuel Increase	0.0068	0.0072	0.0081	0.0083
Traffic Increase	0.0066	0.0070	0.0081	0.0082
Traffic Decrease	0.0057	0.0065	0.0079	0.0083
Signalling Costs - 0	n/a	0.0066	0.0076	0.0078
Signalling Costs - Double	n/a	0.0070	0.0084	0.0086
OCS Costs: +20%	n/a	0.0069	0.0082	0.0084
OCS Costs: -20%	n/a	0.0068	0.0078	0.0081
Electric Loco Price Decrease	n/a	0.0066	0.0076	0.0080

It is to be expected that scenario 1 would be the most sensitive to an increase in the price of diesel fuel since that scenario is the diesel option. A 47.9% increase in the price of fuel, produced a 9.0% increase in the present value of total costs of scenario 1 compared with 5% for scenario 2 and 1% for each of scenarios 3 and 4.

An increase or decrease in traffic levels had the most significant impact of the present value of total costs of scenario 1. A 20% increase in traffic, measured in seat-kilometres, caused a 23% increase in total costs compared to a 19.7% increase for scenario 2, 17.3% for scenario 3 and 15.6% for scenario 4. The same percentage decreases held for a decrease in traffic. This suggests that the electrification scenarios are less sensitive to changes in traffic levels. One of the reasons for this is that the cost of the OCS infrastructure, which is a large part of the total costs of scenarios 3 and 4, does not change with the change in traffic levels under the assumptions adopted in this study.

A change in signalling costs, as described, increase or decrease the present value of total costs by 3.1% in scenario 2, 5.2% in scenario 3 and 5.1% in scenario 4. A 30%

decrease in the price of electric locomotives, as expected, has the greatest impact on the cost of scenario 3, which uses electric locomotives throughout the system. The decrease is 4.4%.

Table 14.9 which summarizes the life cycle cost of each scenario under the sensitivity analyses, shows that although the unit costs increase or decrease, the rankings among the scenarios do not change compared to the base case.

14.3 CONCLUSIONS

As would be expected due to the high capital cost of electrification infrastructure, scenarios 3 and 4, the two full electrification scenarios have a significantly higher economic cost than scenario 1 - full dieselization, and scenario 2 - dieselization of the branch lines and electrification of the Lakeshore line only. The differences between the present values of scenarios 2, 3 and 4 from the base case are: +9.7%, +28.8% and +32.3%.

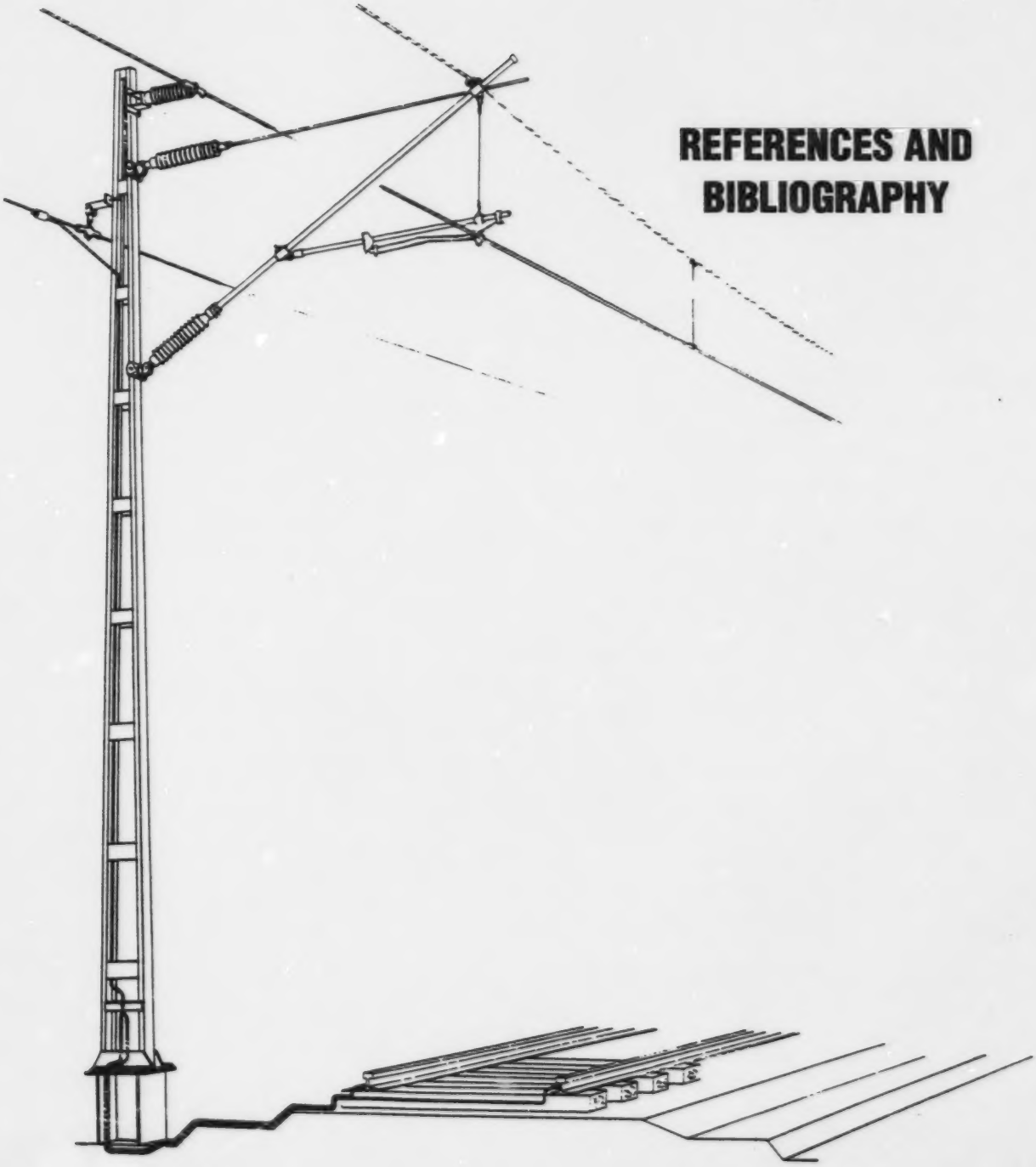
However, there are other considerations in judging the merits of electrification such as the environmental benefits and improvements to service quality.

In the case of service quality, there are modest improvements in running times and low energy cost for off-peak trains which would give off-peak service an operational advantage. A number of significant environmental advantages were shown, specifically in air pollution and noise reduction with some community economic benefits. The only disadvantage is the visual impact of the OCS. There is also a perception in the public eye that an electrified service is faster, more modern and more efficient. This perception arises from visiting and travelling on the electric trains in the U.K., Holland, France and Germany as well as most other European countries and of course, Japan. There is considerable truth to this perception as the high quality passenger train service in those countries would not be possible with only diesel operation.

In summary, scenario 2, electrification of the Lakeshore line achieves most of these benefits at a modest increase in economic cost within the range of accuracy of the

estimates. For practical purposes however, the increase in economic cost of scenarios 2, 3 and 4 over that of scenario 1 - continued full diesel operation (respectively $101.7 million, $301.1 million and $337.6 million) could be viewed as the cost of the environmental benefits and service improvements and evaluated in that context.

15.



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15. REFERENCES AND BIBLIOGRAPHY

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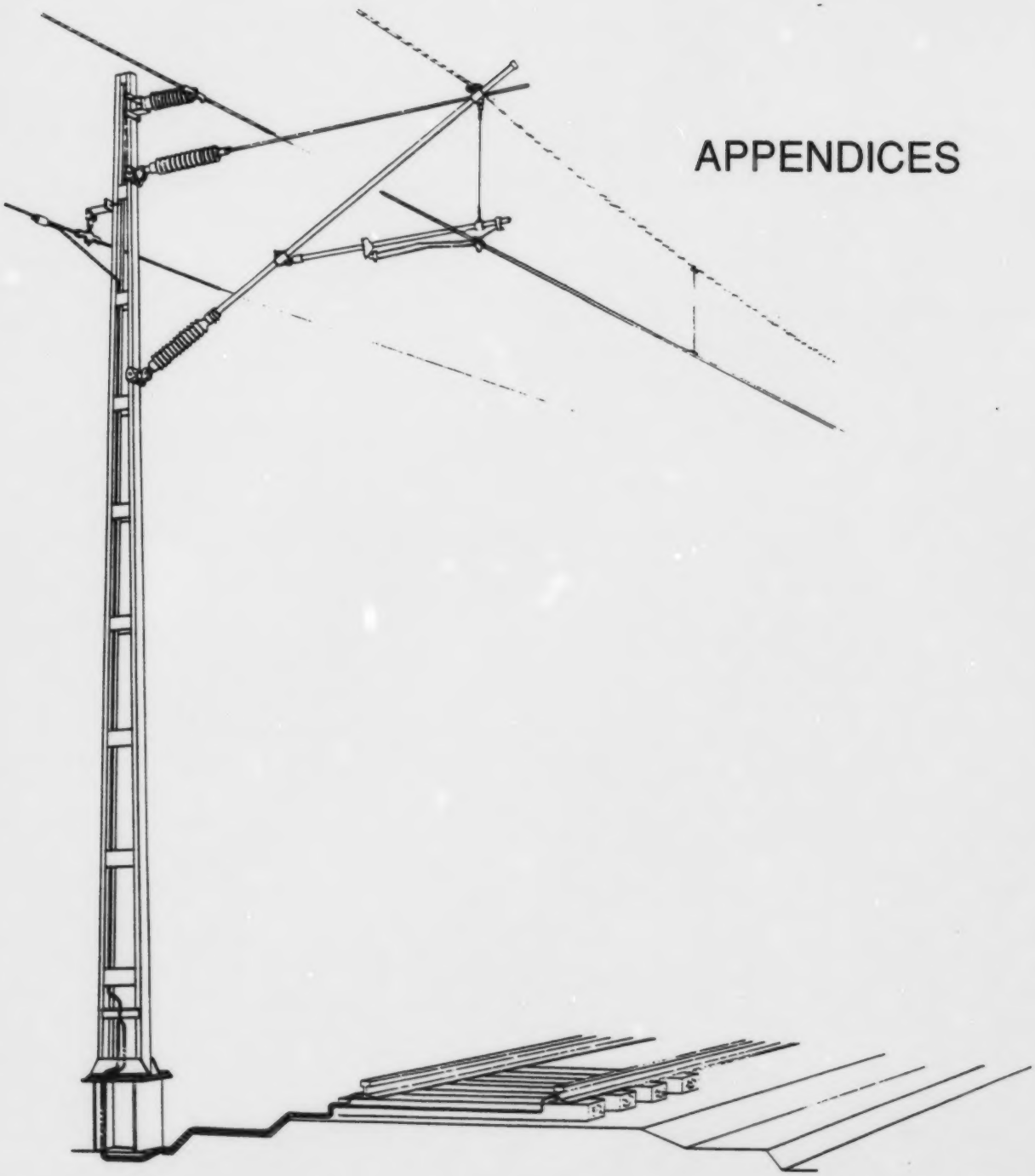
APPENDICES



APPENDICES

A LOCOMOTIVE AND EMU DATA

- A-1 Type F59 PH Diesel Locomotive for GO Transit
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- A-3 EMU Class X10

B TRAIN ROLLING RESISTANCE

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D TRAFFIC AND POWER DEMAND SIMULATIONS

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  - a) Diesel Loco
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- Figure D-2 Oshawa-Hamilton Loco Power Demand
  - a) One minute average
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  - a) One minute average
  - b) Fifteen minute average
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E ELECTRICITY TARIFF

F TRACK LAYOUTS

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H SENSITIVITY ANALYSES

I RAIL ELECTRIFICATION BIBLIOGRAPHY

Appendix A-1

TYPE F59 PH DIESEL LOCOMOTIVE FOR GO TRANSIT

BASIC REQUIREMENTS OF DIESEL-ELECTRIC ROAD PASSENGER LOCOMOTIVE MODEL F59PH WITH MODIFICATIONS AND OPTIONS AS CONTAINED HEREIN

Power for traction	3,000 HP
Power for H.E.P.	500 kW
Number of axles:	
Front truck	2
Rear truck	2
Number of motorized axles:	
Front truck	2
Rear truck	2

Maximum total weight 118,000 kg. (260,000 lbs.)

Maximum differential between trucks at full supplies 1,180 kg. (2,600 lbs.)

Maximum axle load 29,500 kg. (65,000 lbs.)

Maximum operating speed - 136 km/h (83 mph)

Multiple Unit Controls:
Required with locomotive, car and communication control.

Dynamic Braking:
Standard range with self load test and blended air brakes.

Bi-level nominal weight for performance calculations - 70 tons.

Distance over coupler pulling faces	58' 2" (approximately)
Fuel Capacity	8410L (1850 gal. nominal)
Lube Oil System capacity - 12-710G3A	806L (177 I.G.)
- 8V149TI	117.4L (25.8 gal.)
Cooling System capacity - 12-710G3A	727L (160 I.G.)
- 8V149TI	260L (57 I.G.)
Gear Ratio	66:20
Traction Motor	D87B
Wheels	40" dia.
Brake Equipment	26 LUL
	Single shoe brakes
Cab Heat	Electric
Layover Protection	Yes

Multiple Unit Power - Three-Phase HEP trainlines shall be provided for up to two locomotives and ten bi-level cars

Power Plants - The Prime Mover Engine shall be the 12-710G3A model for traction power and shall incorporate all known modifications and design improvements at time of delivery.

The Head End Power Engine shall be the 8V-149TI model and shall incorporate all known modifications and design improvements at the time of delivery.

The power from the Traction diesel engine shall be transmitted to the traction motors by an ac-dc main alternator/rectifier type AR15-CA5A of sufficient capacity to power the traction motors continuously at their maximum continuous ratings.

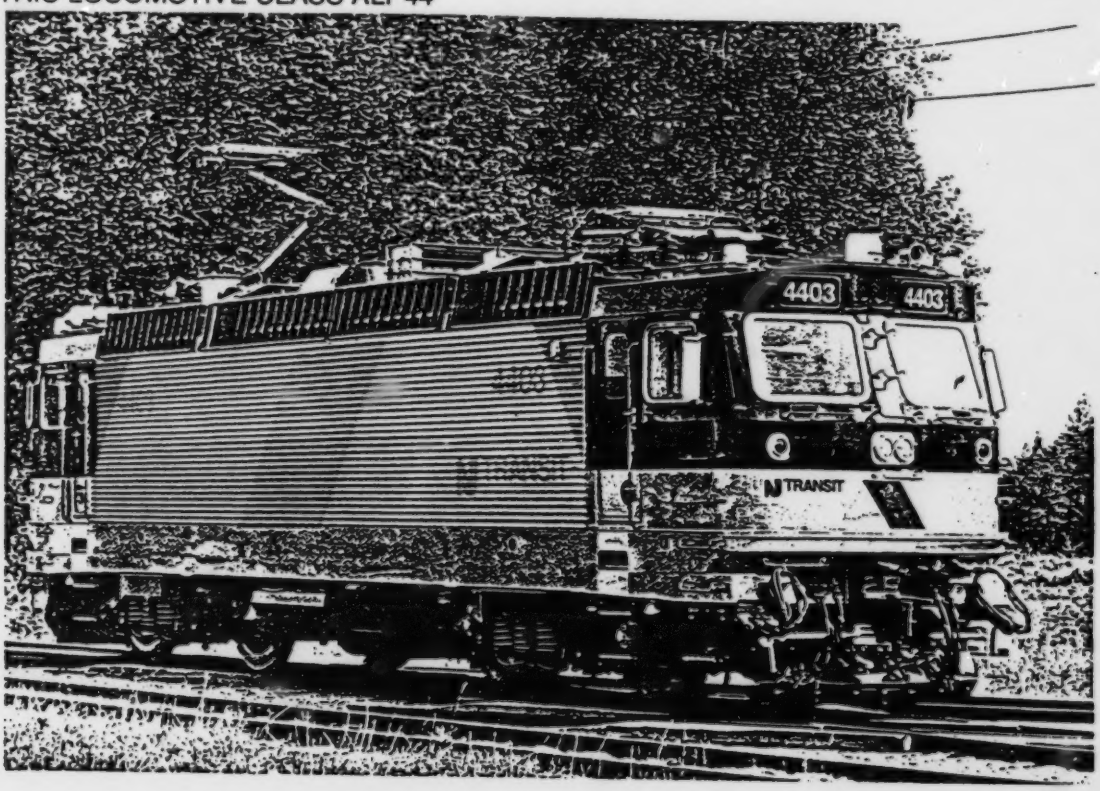
Motors for cooling fans and the inertial blower shall be ac squirrel-cage induction type.

The auxiliary generator, supplying direct current for battery charging or excitation purposes on the locomotive shall be rated at 18 kW. (It shall preferably be of the alternator/rectifier type.)

The engine cooling arrangement shall utilize mechanically bonded radiators and AC fans similar to previous units or equivalent.

All auxiliary systems shall be designed with a view to reducing parasitic power losses and to promote fuel economy.

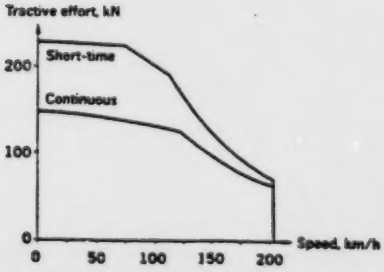
Appendix A-2
ELECTRIC LOCOMOTIVE CLASS ALP44



T-F2731

Electric locomotive Class ALP44 for New Jersey Transit, USA

NJ Transit Corporation operates high speed locomotives from ABB Traction for use in pushpull passenger trains on the North Jersey Coast and Northeast Corridor lines. The design is based on the technology of the well-proven AEM-7-high-speed, all electric thyristor controlled locomotives supplied to SEPTA, the Maryland Dept. of Transportation and to Amtrak for use in its high-speed Metroliner service between Washington and New York, all at speeds up to 200 km/h. The locomotive is equipped with a static converter providing three-phase head-end power for heating, air conditioning and lighting throughout the train.
ABB Traction has been responsible for the entire design, manufacture, asembly and testing of the complete lovomotives.



Main data	
First delivery	1990
Line frequency	25 or 60 Hz
Line voltage at 25 Hz	11 kV
Line voltage at 60 Hz	12.5 or 25 kV
Gauge	1 435 mm
Driving wheel diameter (new)	1 300 mm
Bogie (Truck) wheelbase	2 760 mm
Total wheelbase	10 560 mm
Height over pantograph, down	4 510 mm
Max. widht	3 100 mm
Length over couplers	15 590 mm
Max. speed	201 km/h
Continuos transformer rating	
inkluding carpower at 25 Hz	5 774 kVA
inkluding carpower at 60 Hz	6 560 kVA
Rating as per IEC 349	4 320 kW*
Max. starting effort	230 kN
Axle load max.	23 125 kg
Weight, total	92 500 kg
Number of traction motors	4
Traction motor control	Thyristors
Transmission	Hollow-shaft motor drive
Auxiliary machines	60 Hz, 3-phase
Brake system	Dynamic brake combined with disc brake and tread brake (15%)

*Equivalent to 7000 diesel h.p.

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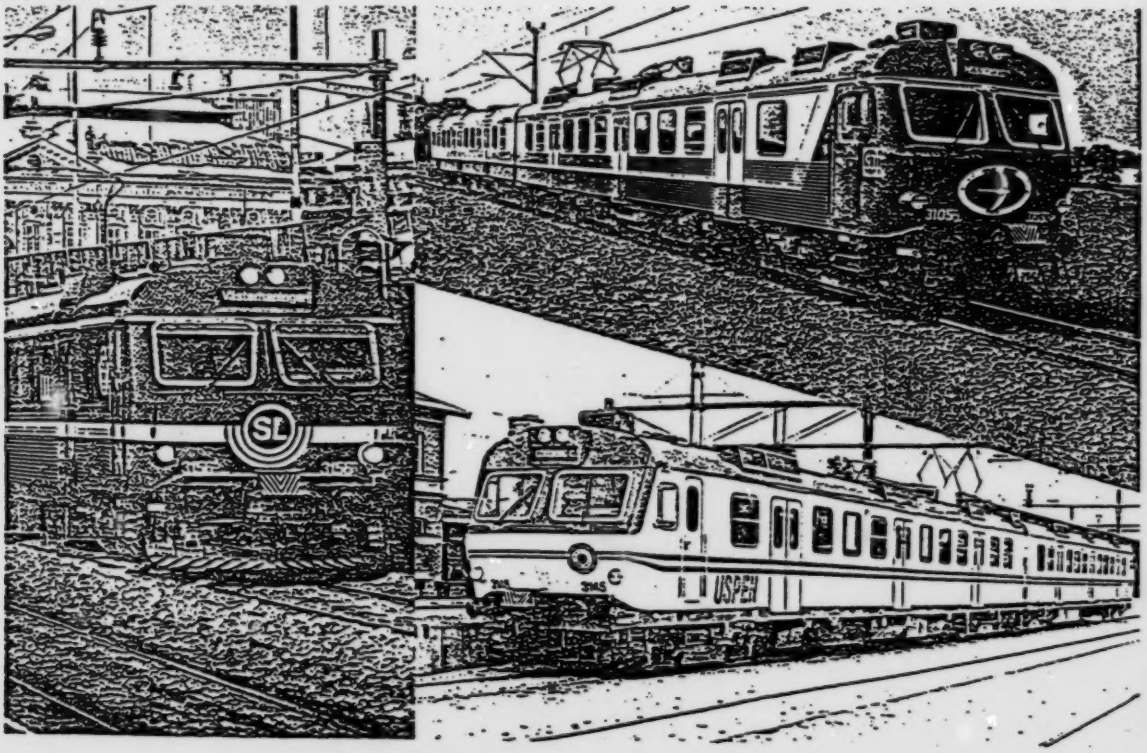
Appendix A-3a
EUROPEAN EMU CLASS X10



Suburban train Class X10

For the growing suburban traffic these two-car units of Class X10 are in service for the local traffic authorities in Stockholm, Gothenburg and Malmö. Each unit consists of one motor car and one driving trailer. Up to five units can be combined into one train at rush time. In Stockholm, X10 units can also be combined with units of the previous generation of suburban trains, the X1.
The design is based on experiences gained from earlier deliveries to Stockholm, Brisbane etc., as well as from high-speed trains in Sweden. A new bogie has been developed to meet the need for the highest possible passenger comfort, as well as for reduced wheel and rail wear. The primary suspension in the bogie permits radial selfsteering of the wheel axles when the train is running through curves.
ABB Traction has supplied the complete trains and is responsible for both mechanical and electrical equipment. ABB Railcar, an ABB Group company, has manufactured the car body.

Main data for a 2-coach unit

First delivery	1982
Max. speed	140 km/h
Line frequency	16 2/3 Hz
Line voltage	15 kV
Gauge	1 435 mm
Height over pantograph, down	4 500 mm
Height of floor from top of rail	1 150 mm
Max. width over body	3 080 mm
Wheel diam. (new)	920 mm
Distance between bogie centres	18 000 mm
Bogie wheelbase	2 600 mm
Length over couplers	49 868 mm
Tare weight	101 000 kg
Seating capacity	184
Standing capacity (normally)	116
Number of traction motors	4
Rating, cont.	4×285 kW
Max. acceleration (0–80 km/h) on level tangent track with full load	0.8 m/s^2
Control system	Thyristors with separately excited traction motors
Transmission	Fully suspended motor and transmission with hollow pinion shaft
Brake system	Dynamic braking combined with disc brake. The motor coach has also tread brakes for cleaning the treads
Emergency brake	Mechanical brake and electro-magnetic track brake

ABB Traction

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ABB
ASEA BROWN BOVERI

Appendix A-3b
EMU UNDERFLOOR EQUIPMENT
(ASEA TRACTION)

Appendix A-3c
EMU ROOF EQUIPMENT
(ASEA TRACTION)

Appendix B
TRAIN ROLLING RESISTANCE FORMULA

The Consultant's VOLTRAN program used for the simulations described in section 8 of this report uses the first four terms of a modified Davis Formula to calculate train rolling resistance. The third and fourth terms are the terms proportional to speed and the square of speed. The fifth and subsequent terms, proportional to higher powers of speed, were found to be negligible in the context of this study.

The train resistance equation was used in the following form.*

The train resistance for a number of identical cars or locos can be expressed as:

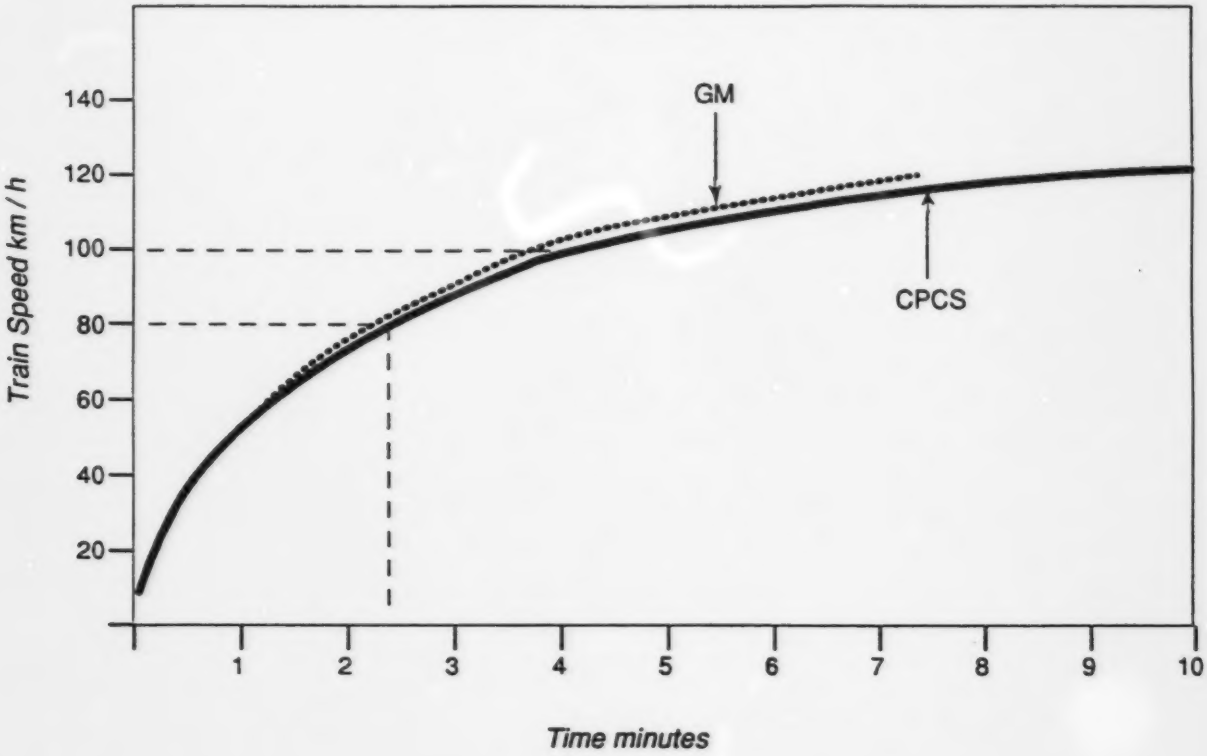
$$R = nW\,(a + bN/W + cV + dAV^2 / 10000W)$$

where

R is the train rolling resistance in kg/metric ton
n is the number of identical cars (locos)
W is the weight of a car (loco) in metric tons
A is the exposed area of car (loco) in m^2
N is the number of axles of car (loco)
V is train speed in km/h
a is a constant = 0.75 for loco's, 0.81 for cars
b is a constant = 8.865
c is a constant = 0.0095
d is a constant = 5.6 for loco's, 6.6 to 11.1 for cars

*As published by the American Railway Engineering Association but converted to metric units.

Appendix C
COMPARISON OF GM AND CPCS
TPC ACCELERATION CURVES



F59 PH 3000 HP - !0 x 70 t cars

APPENDIX D

TRAFFIC AND POWER DEMAND SIMULATIONS

The attached figures present further results of the simulation studies discussed in Section 8 of the main report.

Lakeshore Line, Oshawa-Hamilton

Figures D-1a, D-1b and D-1c show train travel diagrams for the diesel, single locomotive electric and the EMU options respectively during a week day time period between 5:00 am and 10:00 am.

Figures D-2a and D-2b illustrate the daily power demand curve using one minute averaging and 15 min. averaging (15 min. integrated demand) respectively, for the ABB APL44, 4500 kW locomotive hauling 10 bi-level cars.

Figures D-3a and D-3b illustrate the daily power demand curve using one minute averaging and 15 min. averaging (15 min. integrated demand) respectively, for an EMU with 5 units similar to the ABB X10 EMU's (Section 8.3.1 refers).

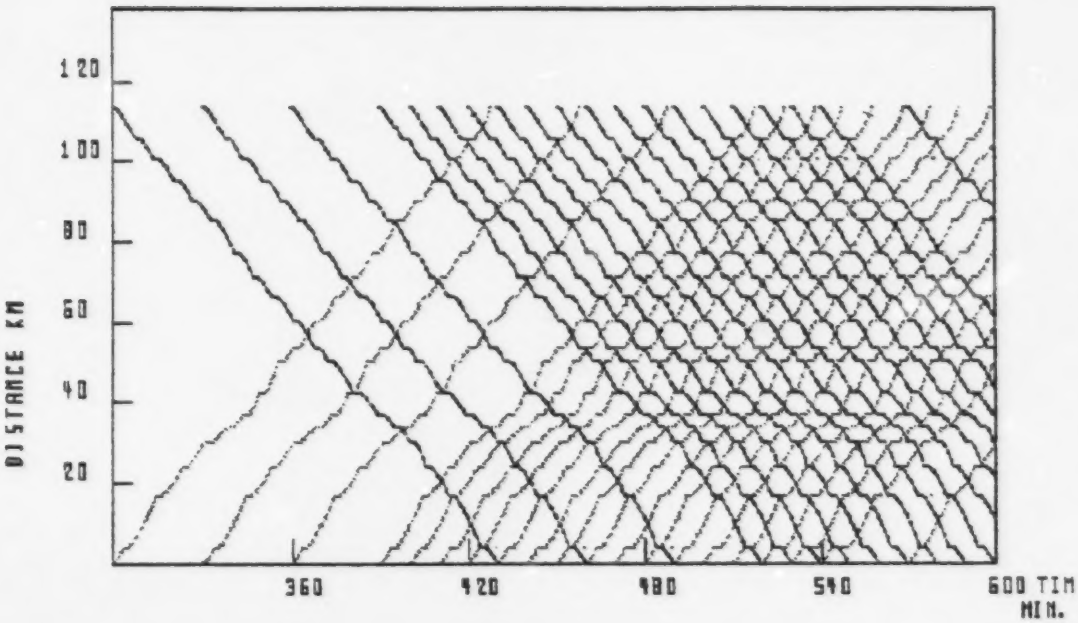
Richmond Hill Line

Figures D-4a, D-4b and D-4c show train travel diagrams for the diesel, single locomotive electric and the EMU options respectively during a week day time period between 5:00 am and 10:00 am.

Figures D-5a and D-5b illustrate the daily power demand curve using one minute averaging and 15 min. averaging (15 min. integrated demand) respectively, for the ABB APL 44, 4500 kW locomotive hauling 10 bi-level cars.

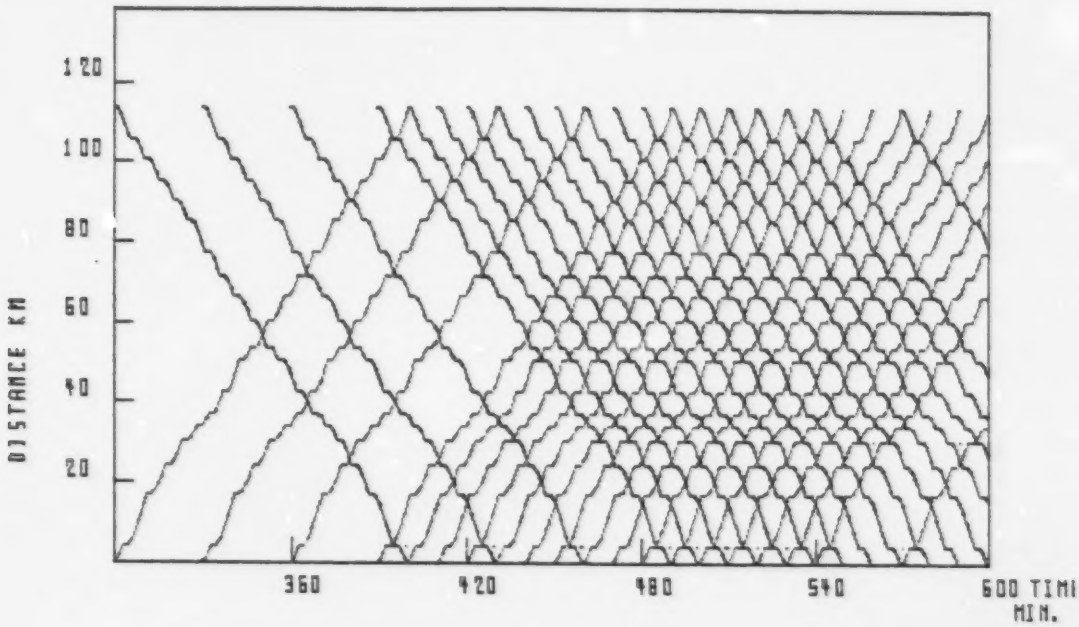
Figures D-6a and D-6b illustrate the daily power demand curve using one minute averaging and 15 min. averaging (15 min. integrated demand) respectively, for an EMU with 5 units similar to the ABB X10 EMU's.

Appendix D-1a



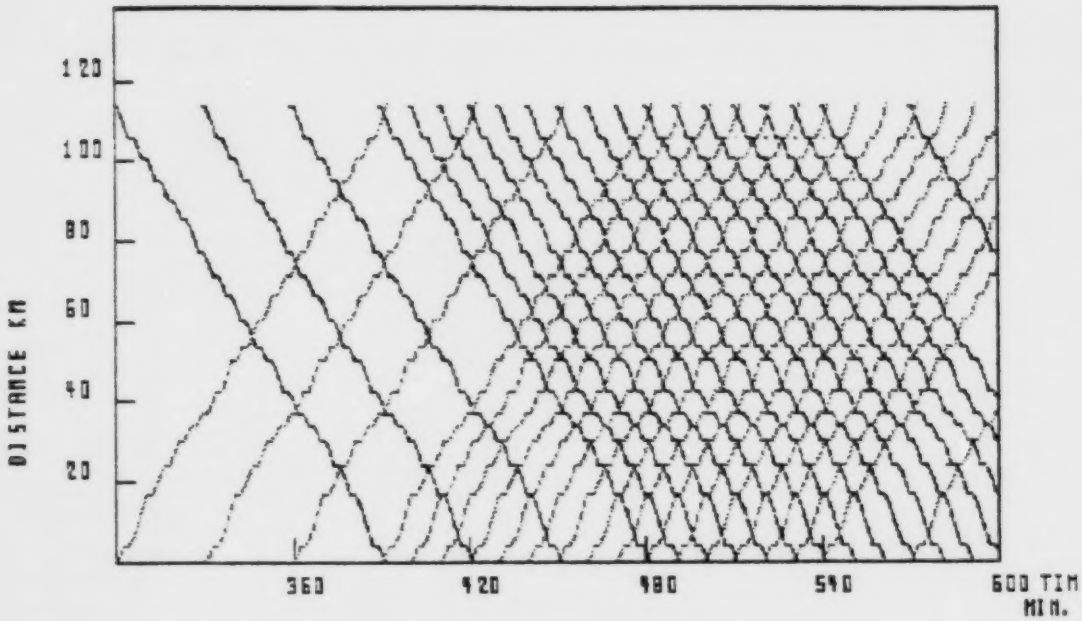
Oshawa-Hamilton Line Daily Train Travel Diagram
Train frequency off-peak/peak 30/10 min.
1-GM F59PH 3000 HP diesel loco. - 10-70t cars

Appendix D-1b



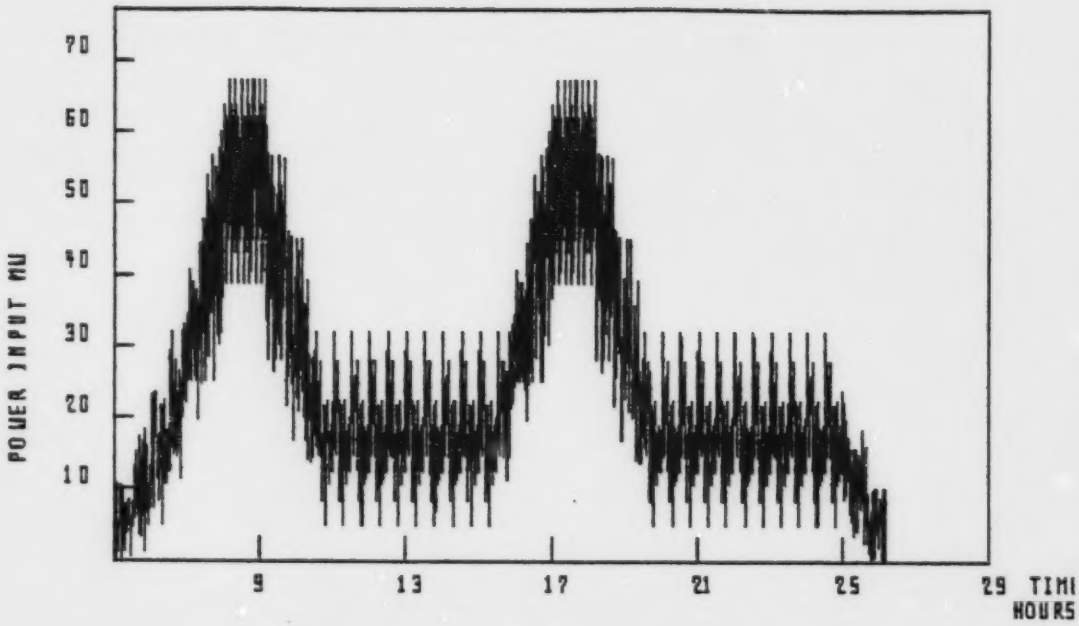
Oshawa-Hamilton Train Travel Diagram 5 AM to 10 AM
Train frequency off-peak/peak 30/10 min.
1-ABB APL44 electric loco. - 10-70t bi-level cars

Appendix D-1c



Oshawa-Hamilton train Travel Diagram 5 AM to 10 AM
Train frequency off-peak/peak 30/10 min.
5-ABB X10 type EMU's - equiv. trailing 700t

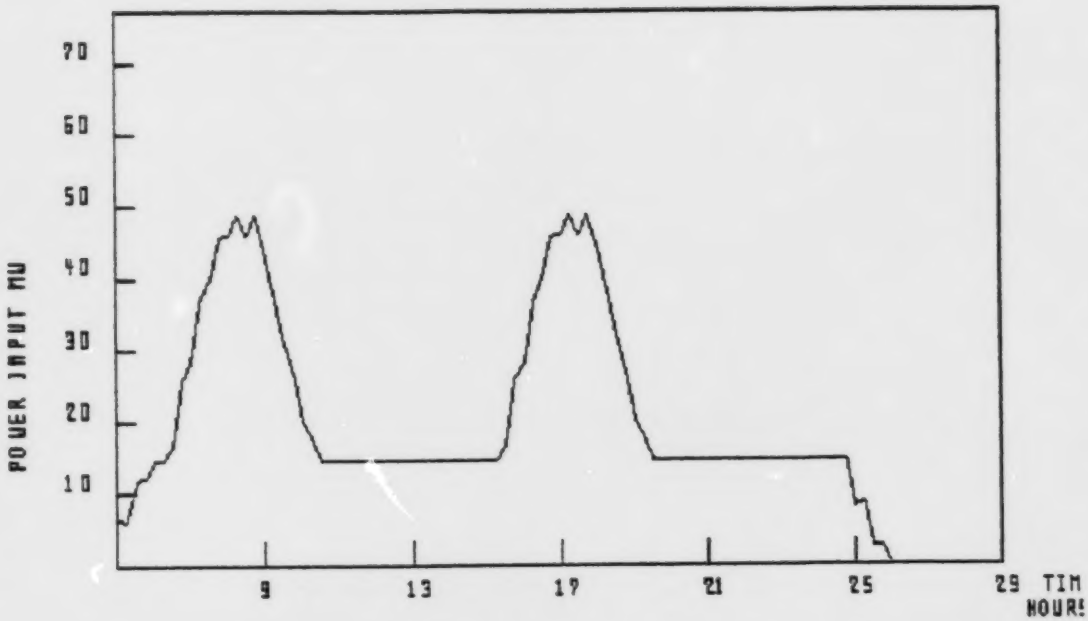
Appendix D-2a



Oshawa-Hamilton Daily 1 min. Power Demand
Train frequency off-peak/peak 30/10 min.
1-ABB APL44 4500 kW electric loco. - 10-70t cars

TOTAL ENERGY OVER KM 0 TO 114	=	617.5 MWH
AVERAGE POWER	=	25.7 MW
PEAK POWER 1 MIN. AVG.	=	67.3 MW
LOAD FACTOR	=	38.2 %

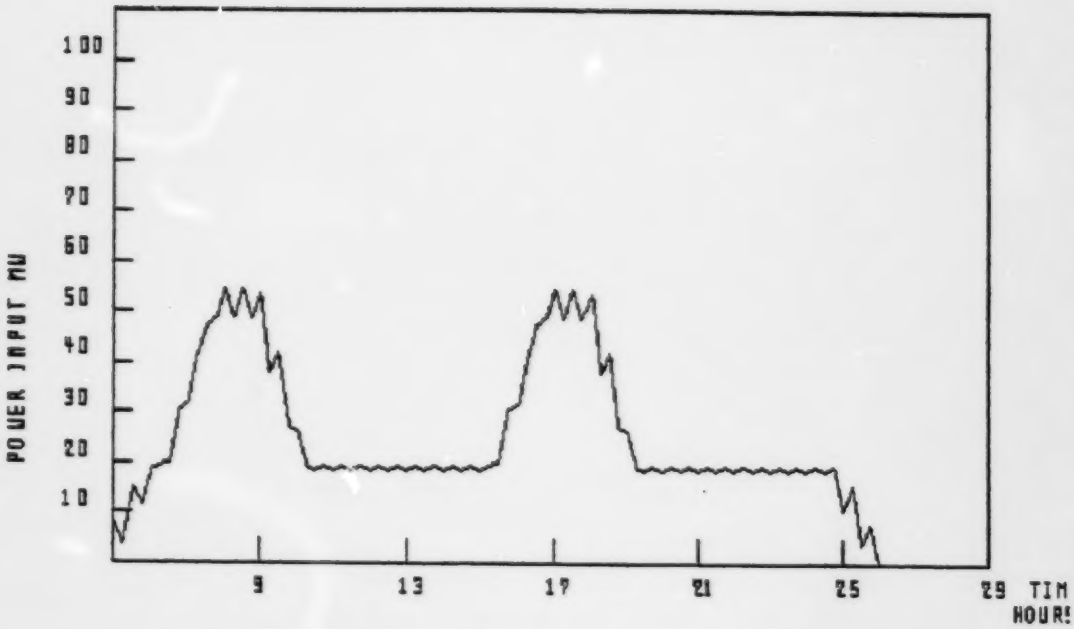
Appendix D-2b



Oshawa-Hamilton Line Daily Integrated 15 min. Demand
Train frequency off-peak/peak 30/10 min.
1 ABB APL44 , 4500 kW electric loco., 10-70t cars

TOTAL ENERGY OVER KM 0 TO 114	=	617.6 MWH
AVERAGE POWER	=	25.7 MW
PEAK POWER 15 MIN. AVG.	=	48.7 MW
LOAD FACTOR	=	52.8 %

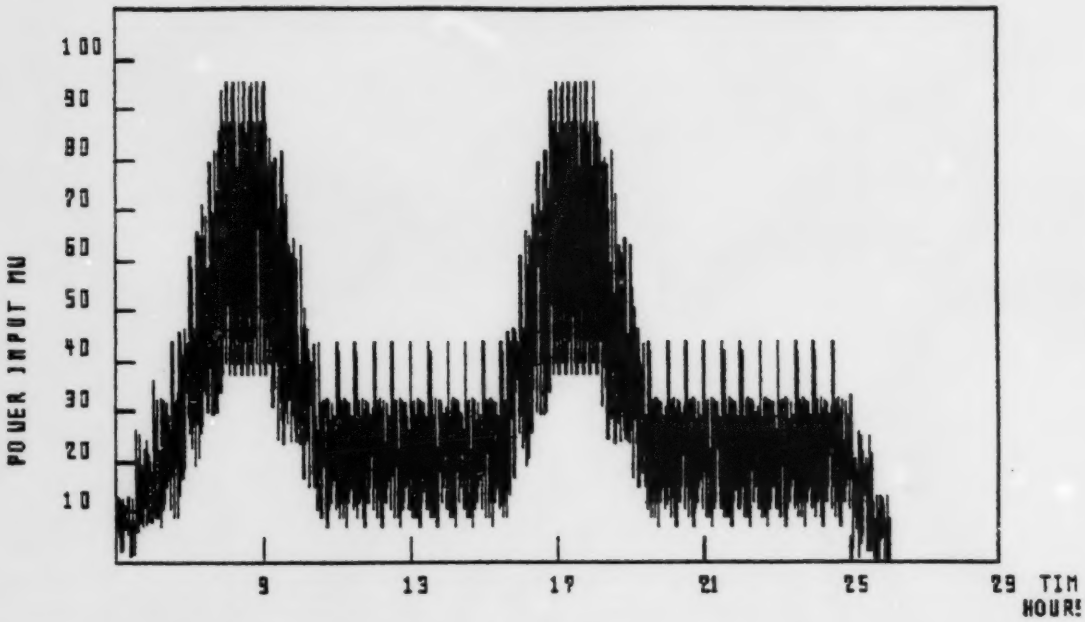
Appendix D-3a



Oshawa-Hamilton Line Daily 15 min. Power Demnad
Train frequency off-peak/peak 30/10 min.
5-ABB X10 type EMU's - 700t equ. trailing

TOTAL ENERGY OVER KM 0 TO 114	=	781.9 MWH
AVERAGE POWER	=	29.2 MW
PEAK POWER 15 MIN. AVG.	=	54.7 MW
LOAD FACTOR	=	53.5 %

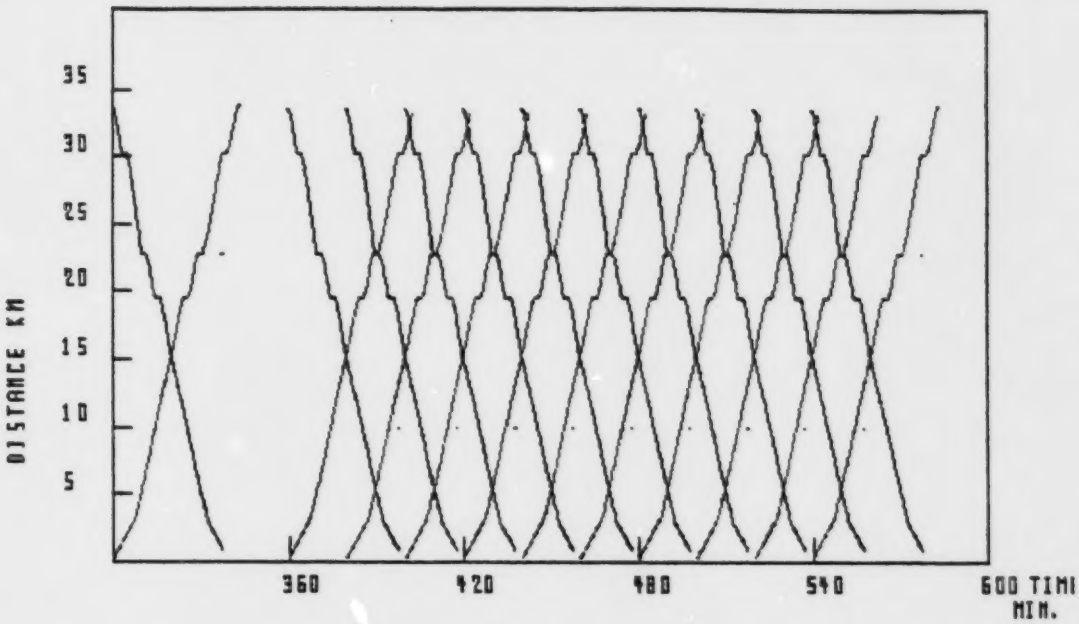
Appendix D-3b



Oshawa-Hamilton Line Daily 1 min. Power Demand
Train frequency off-peak/peak 30/10 min.
5-ABB X10 type EMU's - 700t equ. trailing

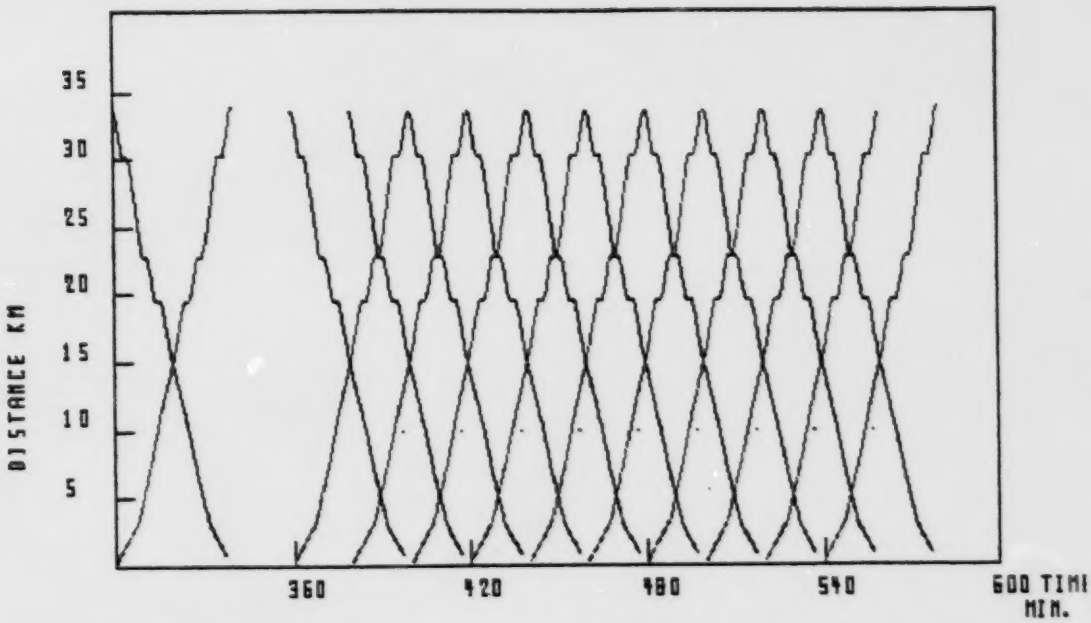
TOTAL ENERGY OVER KM 0 TO 114	=	701.9 MWH
AVERAGE POWER	=	29.2 MW
PEAK POWER 1 MIN. AVG.	=	95.2 MW
LOAD FACTOR	=	30.7 %

Appendix D-4a



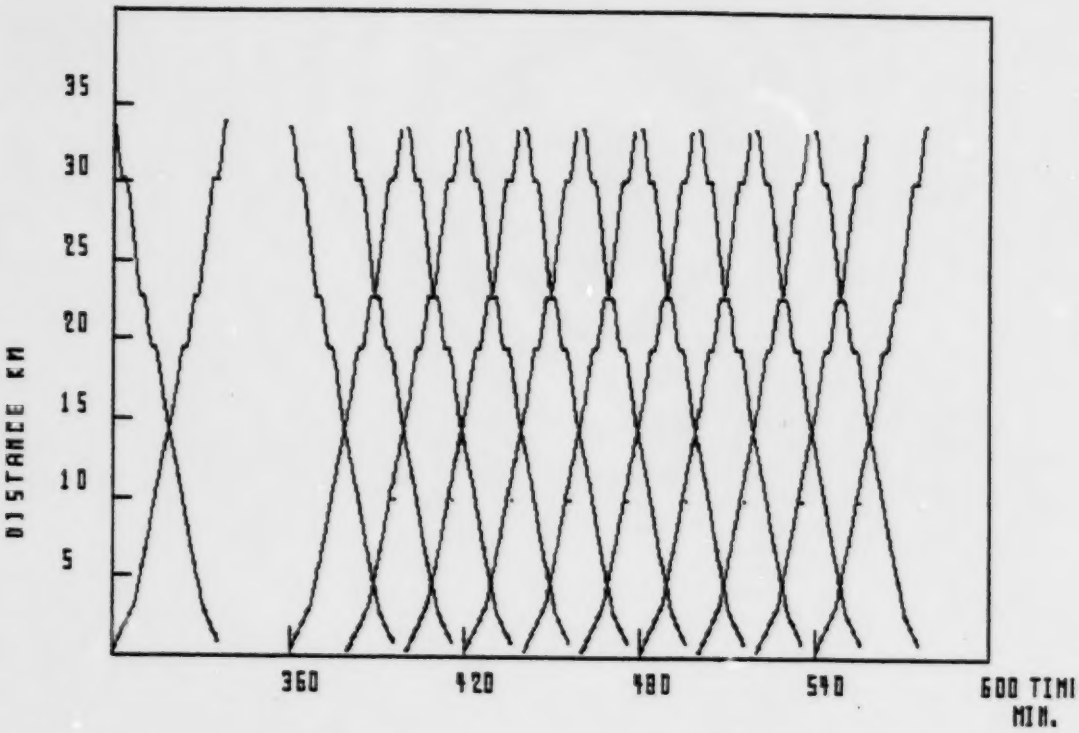
Richmond Hill Line Train Travel Diagram 5 AM to 10 AM
Train frequency off-peak/peak 60/20 min.
GM F59PH 3000 HP diesel loco. - 10 70t cars

Appendix D-4b



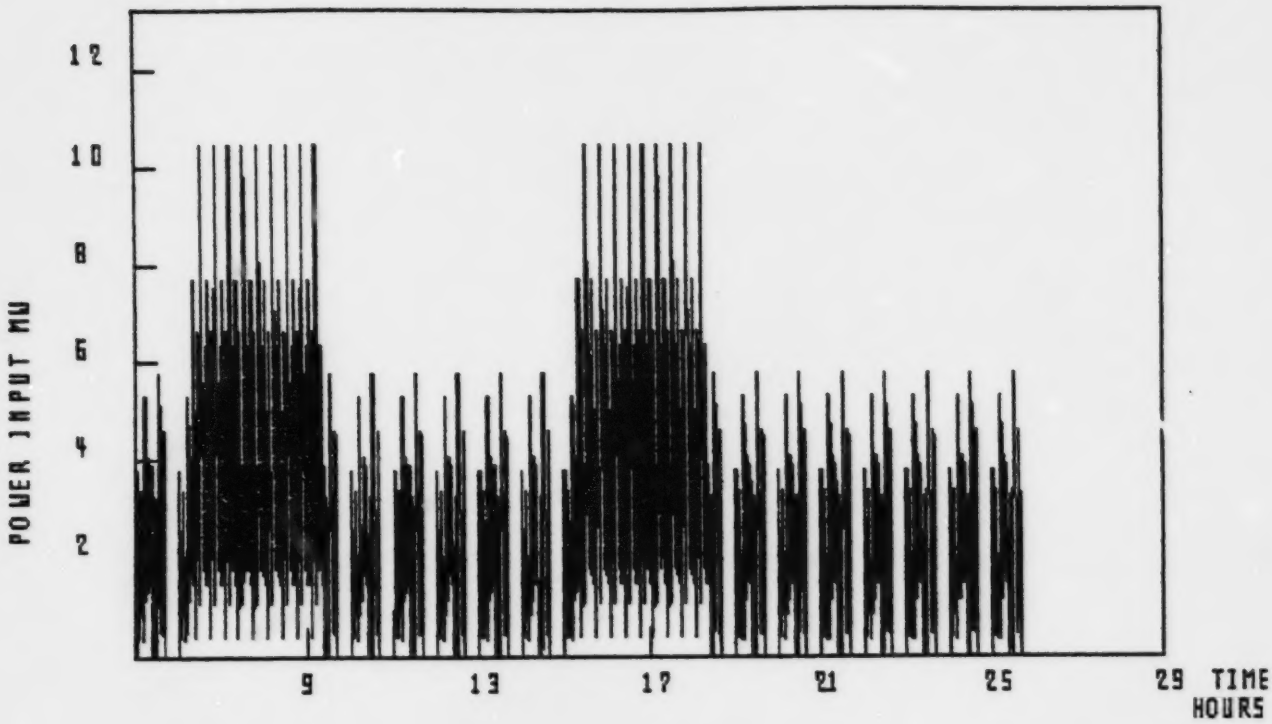
Richmond Hill Line Train Travel Diagram 5 AM to 10 AM
Train frequency off-peak/peak 60/20 min.
1 ABB APL44 4500 kW electric loco. - 10-70t cars

Appendix D-4c



Richmond Hill Line Train Travel Diagram 5 AM to 10 AM
Train frequency off-peak/peak 60/20 min.
5 - ABB X10 type EMU's - 700t equiv. trailing load

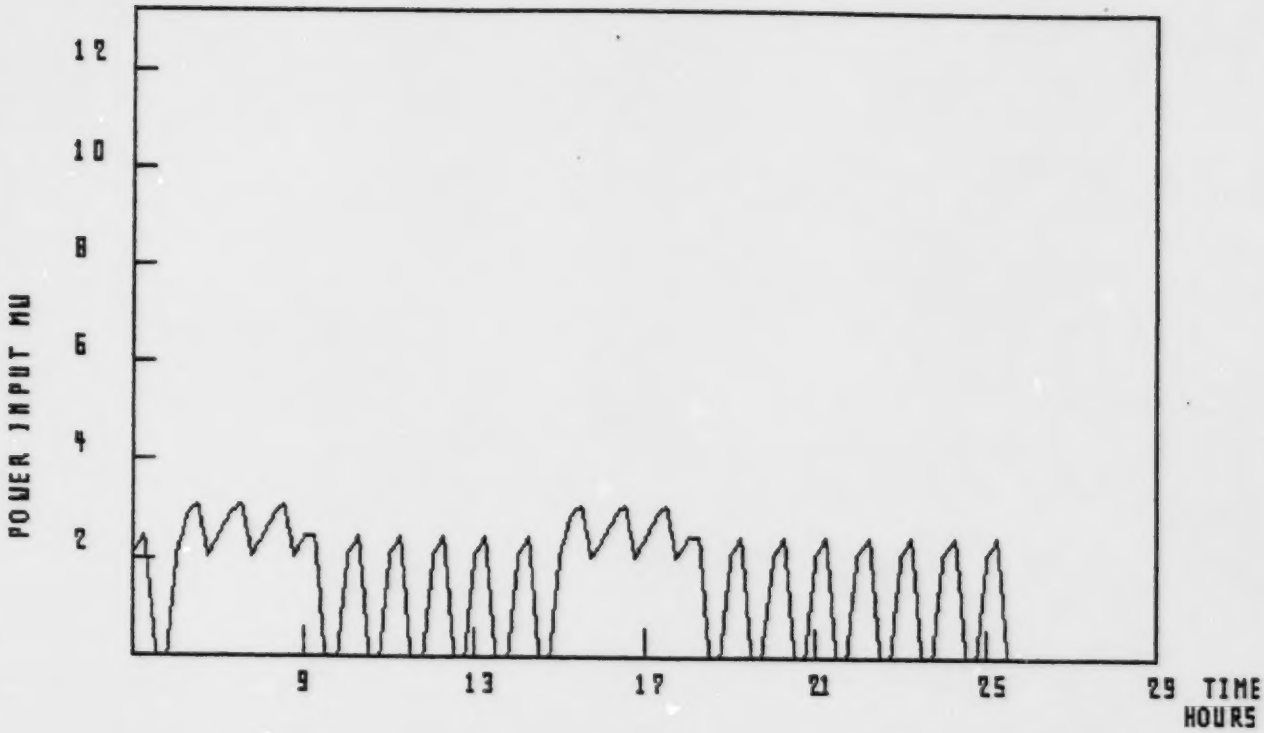
Appendix D-5a



Richmond Hill Line Daily Load Curve
Train frequency off-peak/peak 60/20 min.
1 - ABB APL44 4500 kW electric loco. - 10-70t cars

TOTAL ENERGY OVER KM 0 TO 34	=	56.3 MWH
AVERAGE POWER	=	2.3 MW
PEAK POWER 1 MIN. AVG.	=	10.4 MW
LOAD FACTOR	=	22.5 %

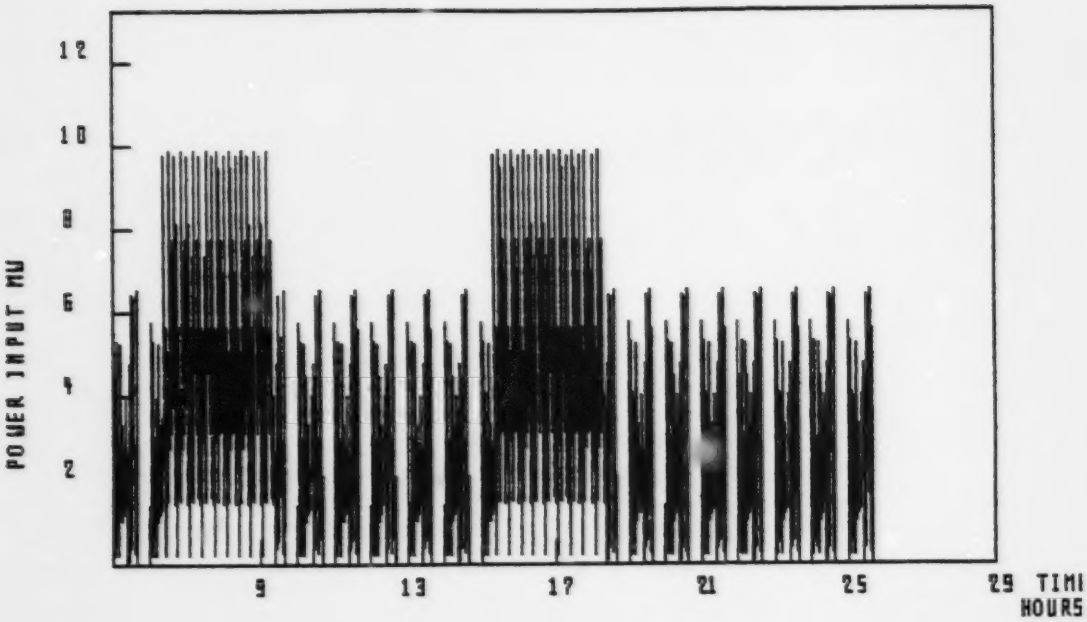
Appendix D-5b



Richmond Hill Line Daily 15 min. Load Curve
Train frequency off-peak/peak 60/20 min.
1 - ABB APL44 4500 kW electric loco. - 10-70t cars

TOTAL ENERGY OVER KM 0 TO 34	=	57.2 MWH
AVERAGE POWER	=	2.4 MW
PEAK POWER 15 MIN. AVG.	=	3.1 MW
LOAD FACTOR	=	76.7 %

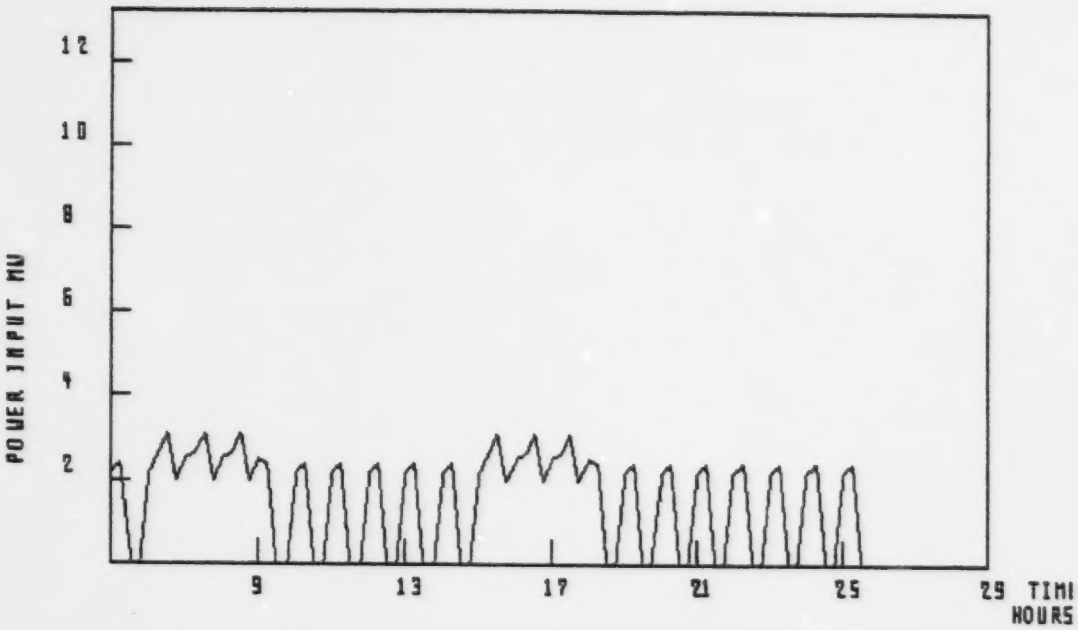
Appendix D-6a



Richmond Hill Line Daily Load Curve
Train frequency off-peak/peak 60/20 min.
5 - ABB X10 type EMU's - 700t equiv. trailing load

TOTAL ENERGY OVER KM 0 TO 34	=	57.9	MWH
AVERAGE POWER	=	2.4	MW
PEAK POWER 1 MIN. AVG.	=	9.9	MW
LOAD FACTOR	=	24.5	%

Appendix D-6b



Richmond Hill Line Daily Load Curve 15 min. Demand
Train frequency off-peak/peak 60/20 min.
5 - ABB X10 type EMU's - equ. trailing load 700t

TOTAL ENERGY OVER KM 0 TO 34	=	57.9 MWH
AVERAGE POWER	=	2.4 MW
PEAK POWER 15 MIN. AVG.	=	3.1 MW
LOAD FACTOR	=	77.6 %

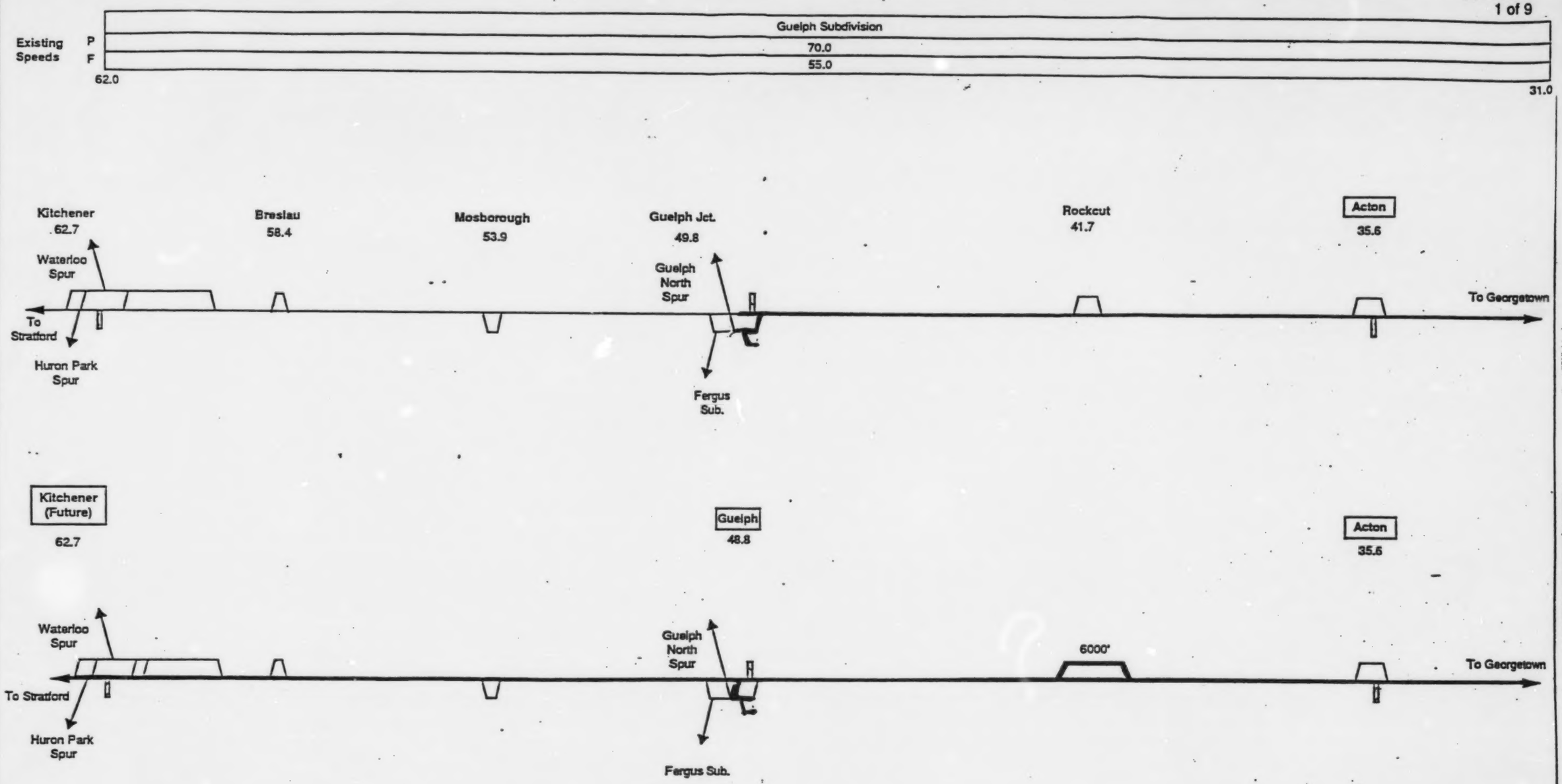
SECTION 2 TABLE 4
ONTARIO HYDRO – RETAIL RATES – GENERAL SERVICE OVER 5000 KW – TIME OF USE
JULY 1, 1991

ONTARIO HYDRO (DIRECTS)	DEMAND CHARGES PER KW					
	230 KV $		115 KV $		UNDER 115 KV $	
	WINTER	SUMMER	WINTER	SUMMER	WINTER	SUMMER
FIRM	10.49	7.48	10.77	7.76	11.51	8.50
INTERRUPTIBLE	9.19	6.18	9.47	6.46	10.21	7.20
DDS1	7.07	4.06	7.35	4.34	8.09	5.08
DDS2	8.44	5.43	8.72	5.71	9.46	6.45
DDS3	8.78	5.77	9.06	6.05	9.80	6.79

ENERGY CHARGE

WINTER		SUMMER	
PEAK ¢/KW	OFF PEAK ¢/KWH	PEAK ¢/KWH	OFF PEAK ¢/KWH
3.76	2.82	3.32	2.02

Peak hours 0700 - 2300
Off Peak 2300 - 0700



LEGEND

- Existing Track
- Proposed Track
- Signal Location
- Station Platform

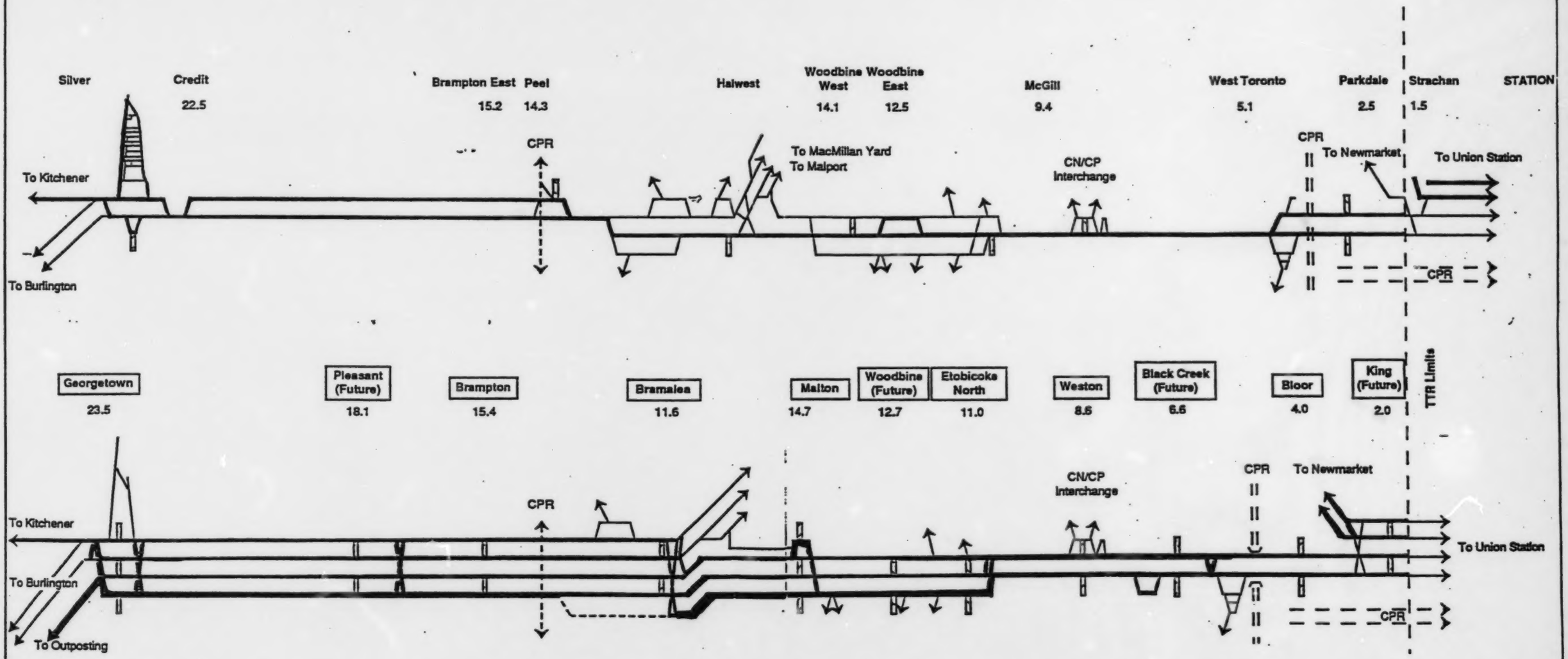
NOTE: Industrial Support Trackage and Local Industries NOT shown.

Figure 1
TRANSIT EXPANSION PROGRAM
Long Term Georgetown Route
Guelph Subdivision
Mile 30.0 to 62.7

11 July 1991

	Halton Subdivision					Weston Subdivision					
70.0	50.0	70.0	50.0	60.0	←50.0	80.0	55.0	TTR	P	EXISTING
55.0	50.0	55.0	50.0	55.0	←50.0	60.0	35.0	TTR	F	SPEEDS

31.0 30.0 / 24.1 22.2 15.7 14.2 11.1 / 17.0 5.3 1.6 0.0



NOTE: Industrial Support Trackage and Local Industries NOT shown.

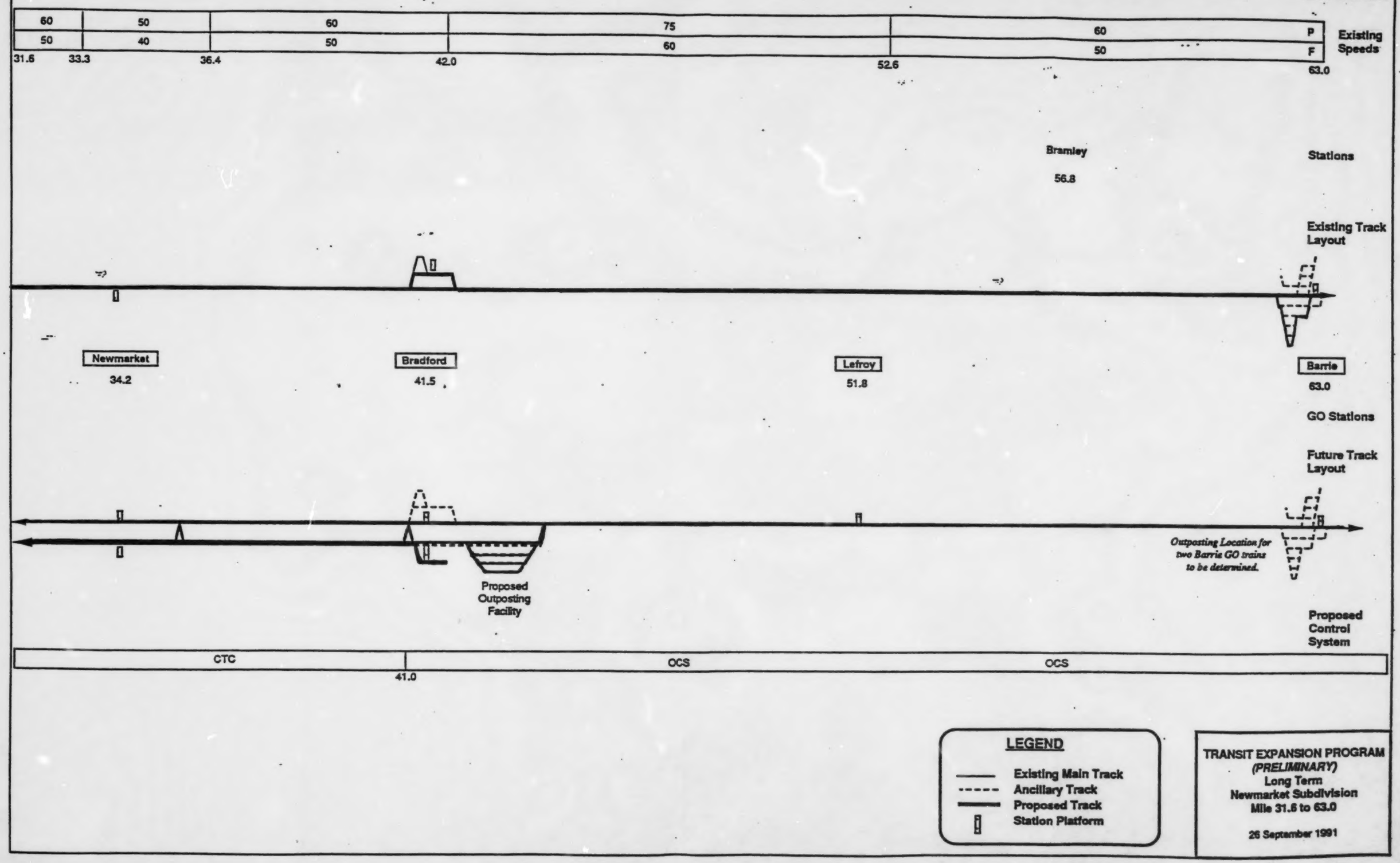
LEGEND

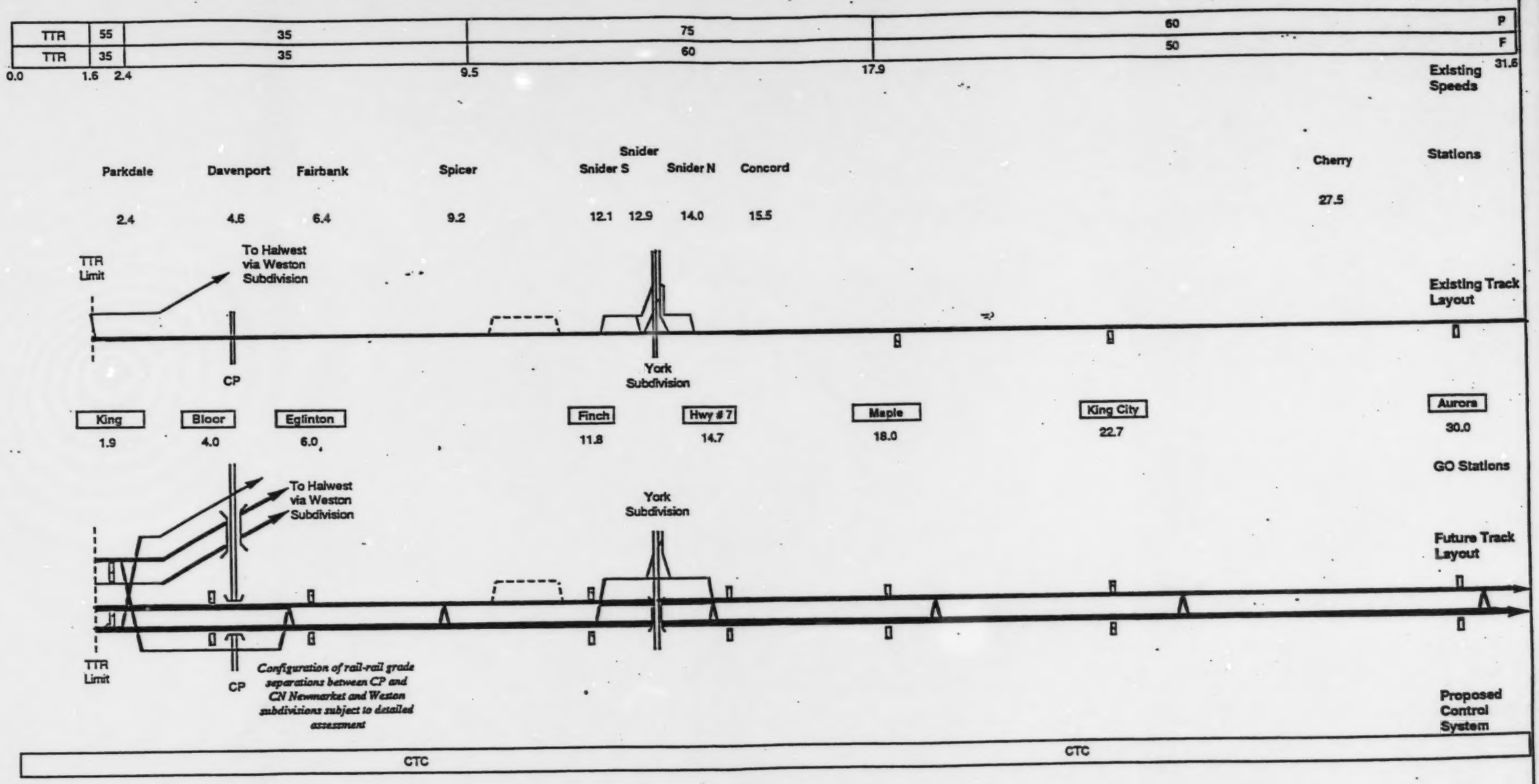
- Existing Track
- Proposed Track
- Station Platform

TRANSIT EXPANSION PROGRAM

Long Term Georgetown Route
Weston and Halton Subdivisions

30 September 1991


60
50
60
75
60
P
50
40
50
60
50
F
Existing Speeds
31.6
33.3
36.4
42.0
52.6
63.0
Bramley
56.8
Stations
Existing Track Layout
Newmarket
34.2
Bradford
41.5
Lefroy
51.8
Barrie
63.0
GO Stations
Future Track Layout
Outposting Location for two Barrie GO trains to be determined.
Proposed Outposting Facility
Proposed Control System
CTC
41.0
OCS
OCS
LEGEND
Existing Main Track
Ancillary Track
Proposed Track
Station Platform
TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Newmarket Subdivision
Mile 31.6 to 63.0
26 September 1991



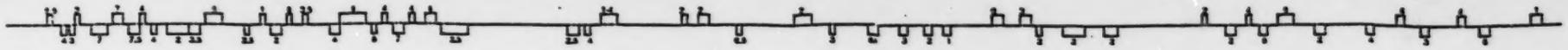
LEGEND

- Existing Main Track
- Ancillary Track
- Proposed Track
- Station Platform

TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Newmarket Subdivision
Mile 2.4 to 31.6

26 September 1991

NOTE: Industrial Support Trackage and Local Industries NOT shown.

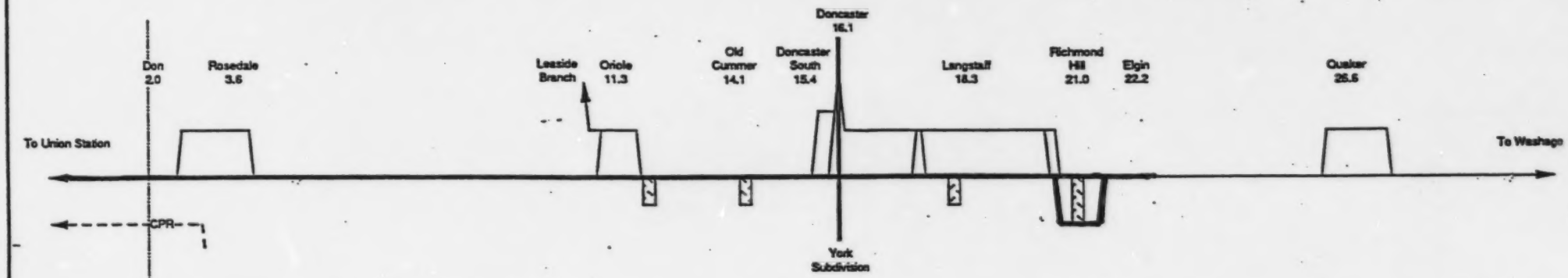


Existing Curves

TTR	30	35	40	35	50	65	60	45	45	70	P
TTR	25	30	35	30	40	50	50	40 (DU 40)	40 (DU 30)	60	F

0.0 1.9 2.0 4.5 6.9 10.0 13.4 16.0 25.0 28.0 29.8 31.0

Existing Speeds

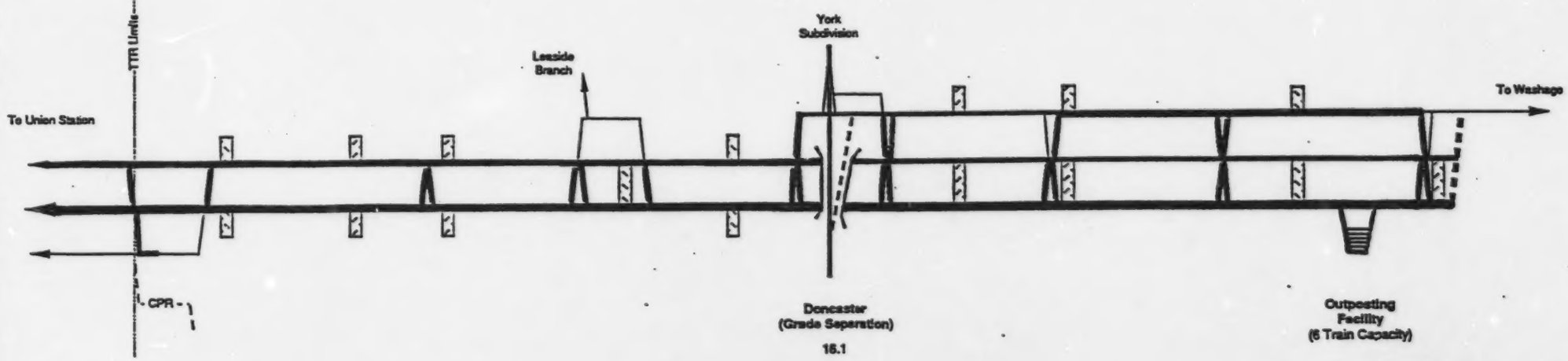


Existing Track Layout

Ataritiri (Future)	Bloor (Future)	Don Mills (Future)	Eglinton (Future)	Oriole	Old Cummer	Langstaff	Richmond Hill	Gormley (Future)	Bloomington (Future)
1.6	3.8	6.4	8.3	12.1	14.1	18.8	21.0	25.7	28.6

Station

Mileage



Future Track Layout

NOTE: Industrial Support Trackage and Local Industries NOT Shown.

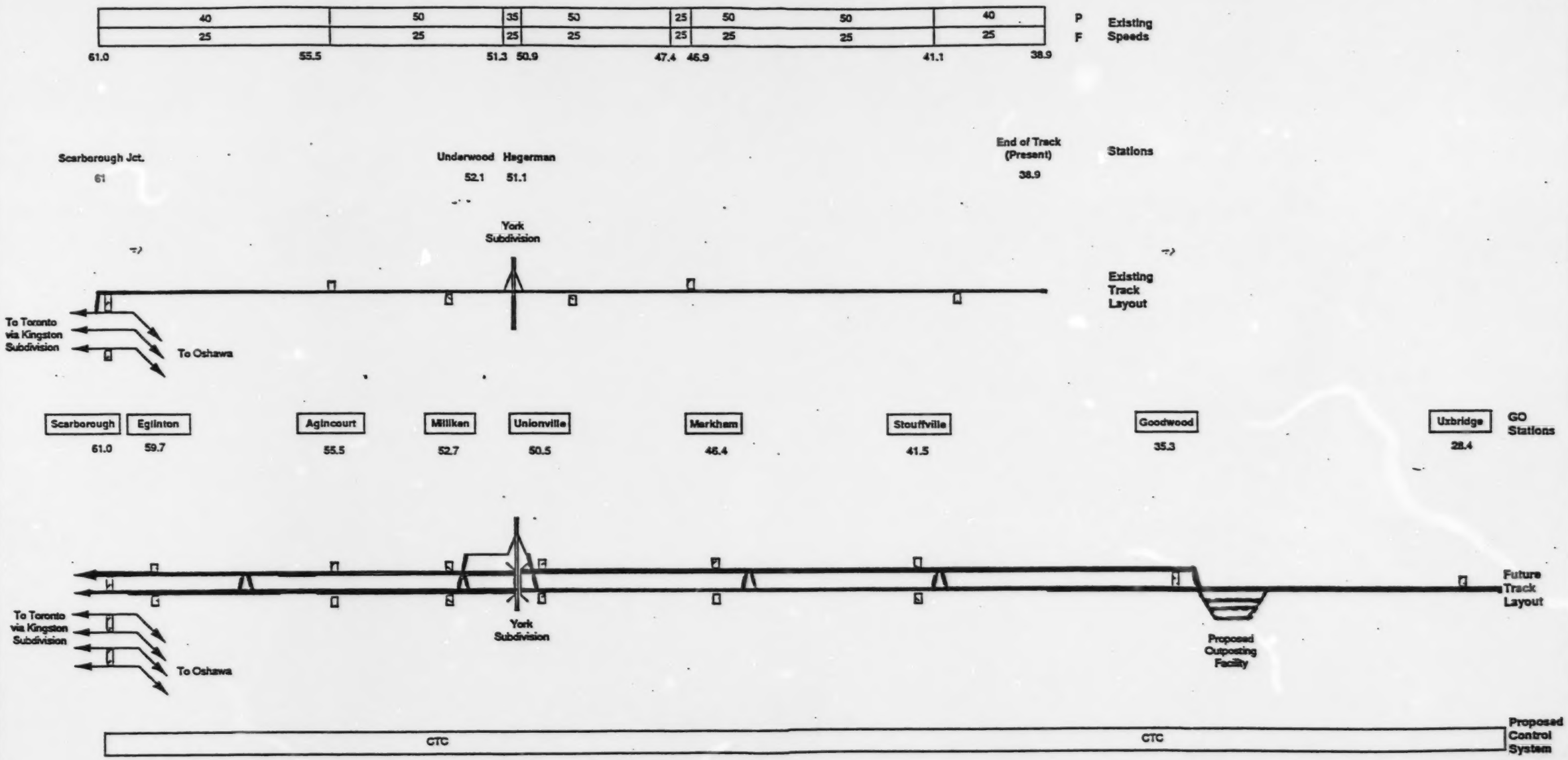
LEGEND

- Existing Track
- Proposed Track
- Future Northeast Leg of Wye
- Station Platform

TRANSIT EXPANSION PROGRAM

Long Term
Bala Subdivision
Mile 1.9 to Mile 30

30 September 1991



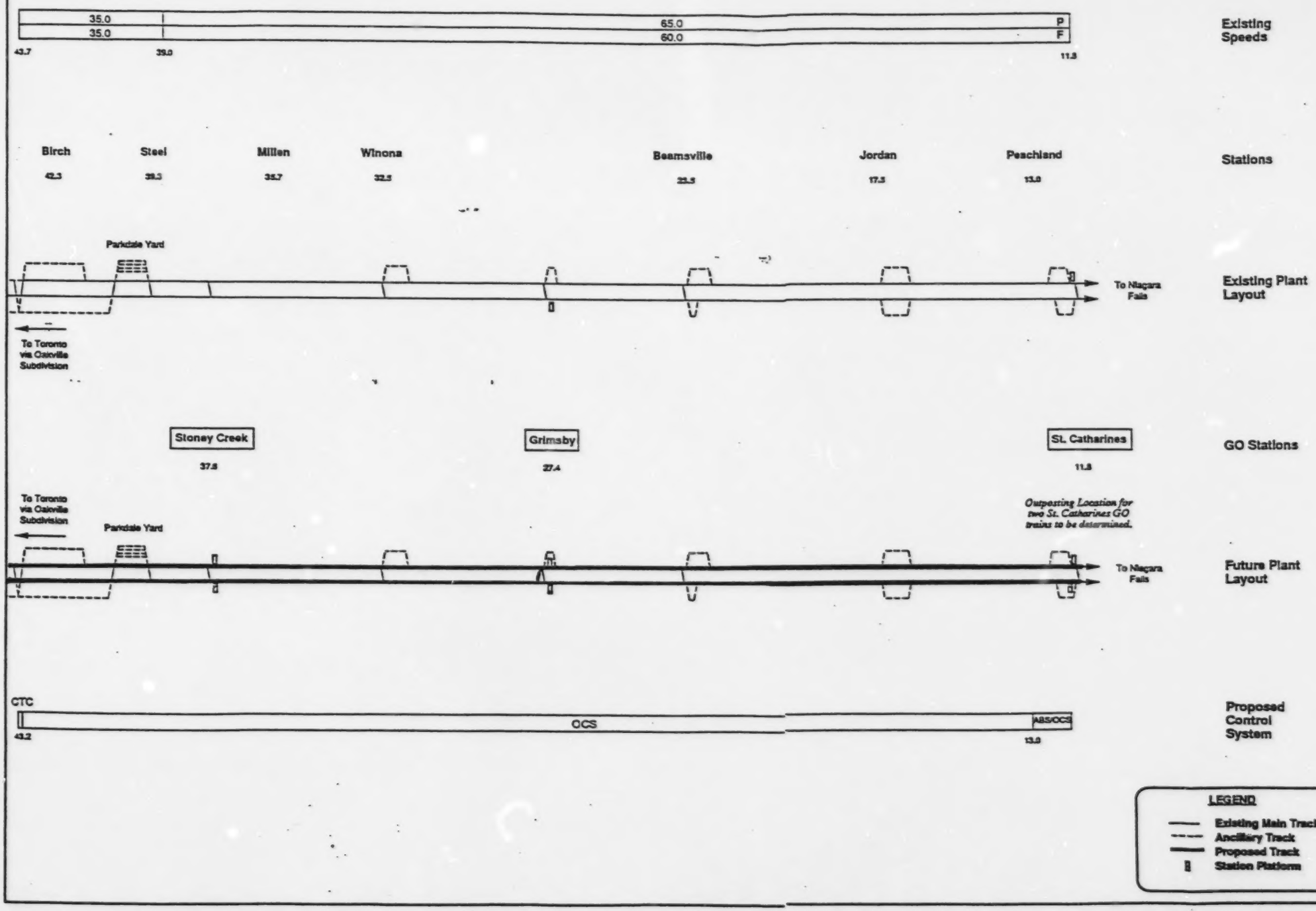
NOTE: Industrial Support Trackage and Local Industries NOT shown.

LEGEND

- Existing Main Track
- Ancillary Track
- Proposed Track
- Station Platform

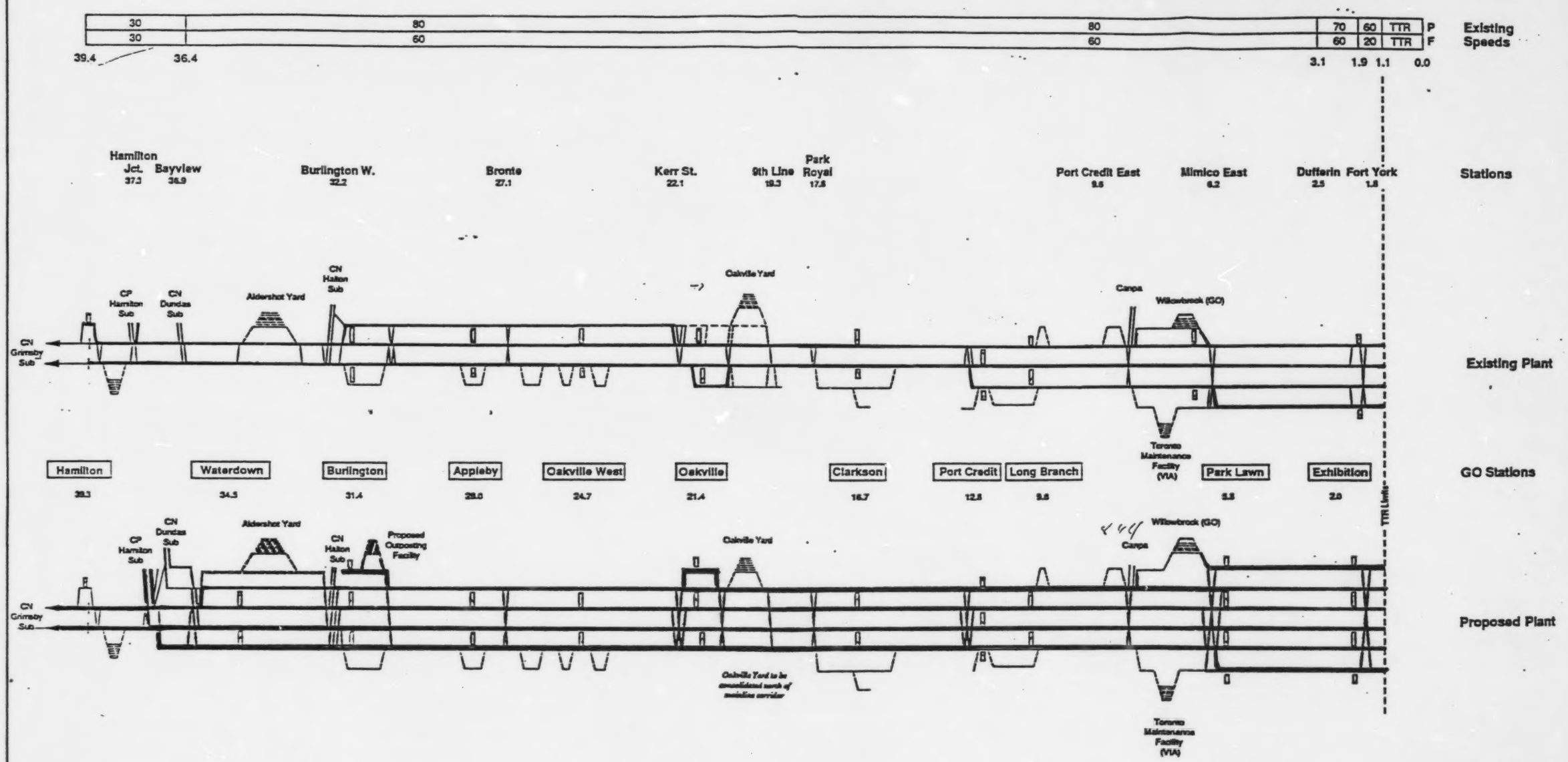
TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Uxbridge Subdivision
Mile 28.4 to 61.0

26 September 1981



TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Grimsby Subdivision
Mile 11.8 to 43.7

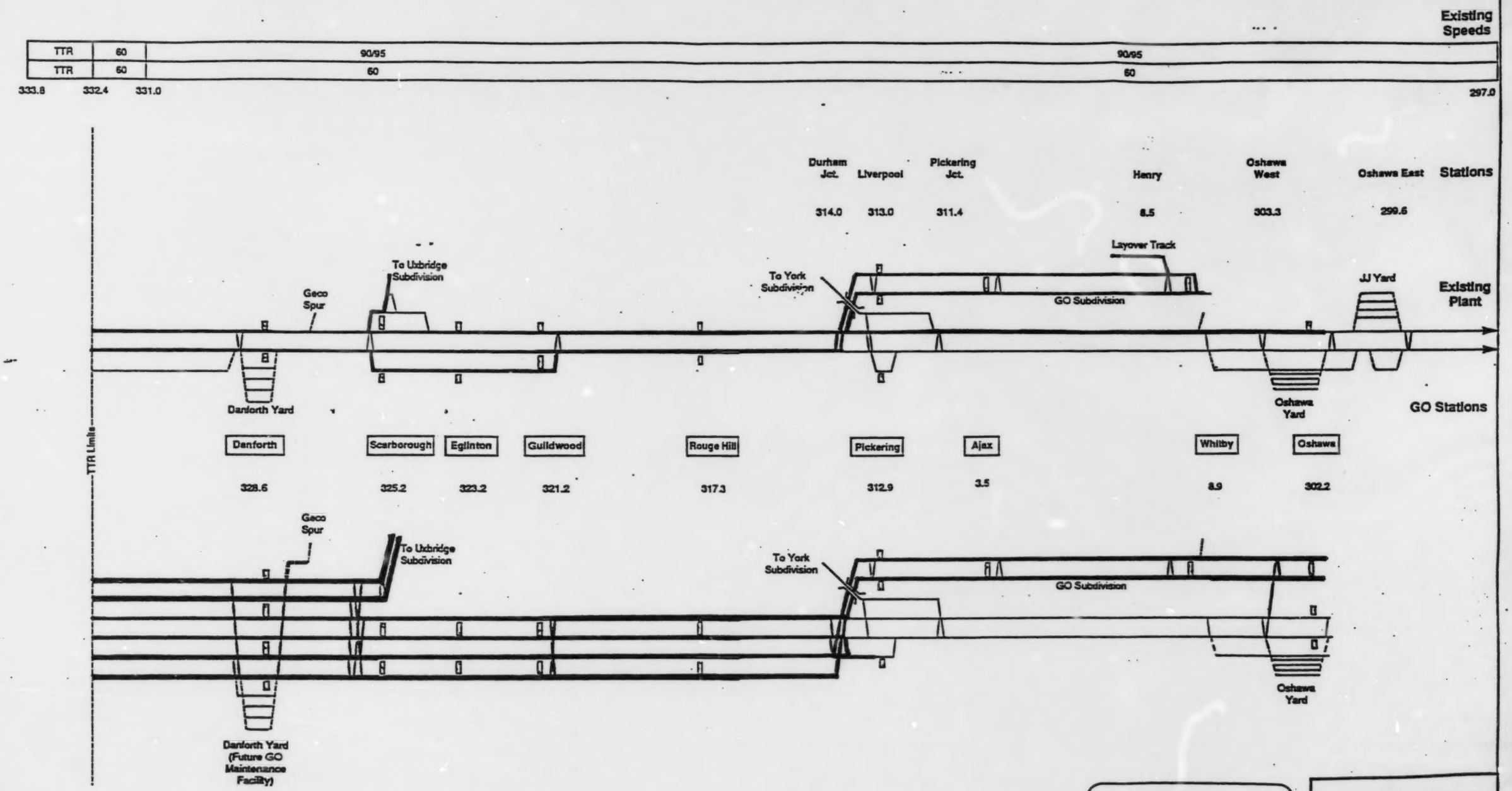
28 September 1991



NOTE: Industrial Support Trackage and Local Industries NOT shown.

TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Oakville Subdivision
Mile 1.1 to 39.3

27 September 1991



NOTE: Industrial Support Trackage and Local Industries NOT shown.

LEGEND

- Existing Main Track
- Ancillary Track
- Proposed Track
- Station Platform

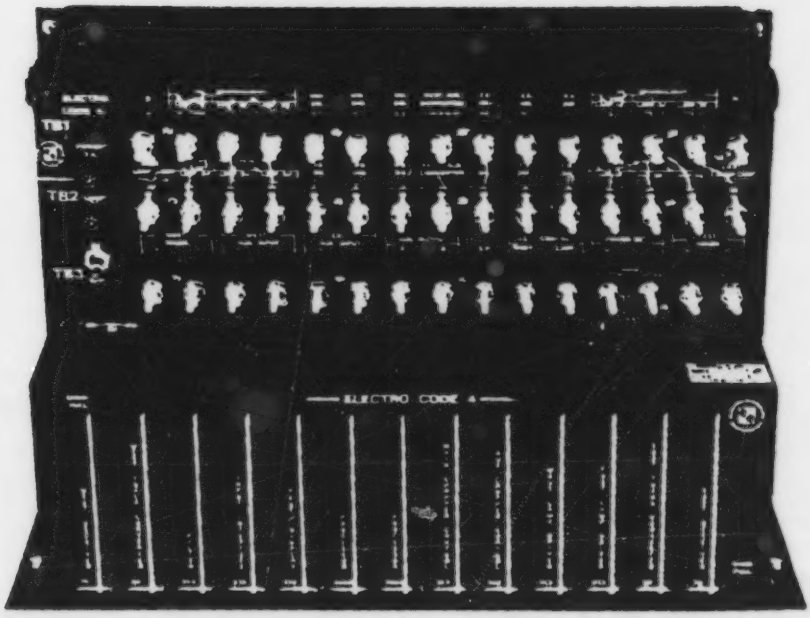
TRANSIT EXPANSION PROGRAM
(PRELIMINARY)
Long Term
Kingston and GO Subdivisions
Mile 297.0 to 332.8

28 September 1991

Appendix G

IM-308

ELECTRO CODE 4 MANUAL



3/87

ELECTRO PNEUMATIC CORPORATION
A wholly-owned subsidiary of
HARMON INDUSTRIES, INC.
P.O. Box 600 • Grain Valley, Missouri 64029 • (816) 249-3112 • Telex 42-5366

REV: A00

06/14/91

ELECTRO CODE 4

INTRODUCTION

Electro Code is a dc track circuit* that is coded at each end to control block signals. It has the advantage of operating without the need for line wires, compared with conventional signal equipment. Electro Code 4 uses fail-safe electronic circuits and microprocessor logic to send and receive track code pulses.

Secure operation is obtained through the use of codes and polarity of the track currents. Seven codes are used for controls and indications, and an eighth code is a part of the tumble-down sequence during traffic reversal.

Codes are designated as Code 1, Code 8, Code 2, Code 3, Code 4, Code 7, Code 5, and Code 6, with each one performing a specific job in the signal control system. These codes have a distinct timing characteristic that can be recognized by the microprocessor decoding logic. (Timing Charts, Page 5 & 6).

Codes are transmitted through the rails between signals, making it possible to detect a train and to provide broken rail protection. Code is transmitted by a D.C. Converter which is turned on during each code pulse. The D.C. Converter produces the track "battery" voltage that forces current through the rails.

The Electro Code Receiver responds to dc currents in the same way as a track relay that follows code. The polarity and level of current must be proper to cause the Receiver to respond.

Code that is received from another signal location is decoded by electronic circuits and microprocessor logic, which produces control voltages to operate signal lamps. Lamp outputs are accessible on terminals to accommodate the various signal requirements.

Two way control of signals is made possible with Electro Code by a synchronizing technique. The transmitted code pulses are .115 seconds long, and they are repeated every 2.8 seconds. This leaves ample time to receive codes from the other direction, as long as they are synchronized.

At intermediate signal locations the directional stick requirements are done logically by the microprocessor. No external relays are required with Electro Code 4 at intermediate signal locations to provide lighted signal aspects, stick circuit operation, and other operating functions normally associated with 4 wire signalling.

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* For ac variant for electrified territory see page 10 below.

Basic Track Circuit

The Electro Code track circuit compares to a coded relay track circuit with bi-directional coding synchronized to work in both directions continuously. A relay code transmitter applies coded battery to the rail and a code following relay at the other end of circuit repeats the information instantly. The Electro Code system uses a 2R converter module to apply a battery pulse to the rail, and a code following 7K receiver module at the other end repeats the information instantly. The leading edge of the first pulse received by the 7K receiver module is used to synchronize the system logic to transmit code battery to the rail with a 2R converter, at the opposite end of the track circuit where a 7K receiver module instantly repeats the track pulse. We now have a track circuit which is transmitting battery pulses from each end of circuit and receiving pulses at each end.

Synchronizing and decoding of code pulses applied to the rails provides the vital track information required to operate a signal system. The Electro Code system transmitts code pulses for approximately 1.4 seconds, which are instantly being decoded at the other end of circuit, then the first transmiter is turned off, the receiver module is made active to receive pulses from the opposite end of the circuit. The synchronizing timing is based on the Electro Code equipment at each end of circuit answering the code pulses received from the opposite end of the track circuit 1.4 seconds after the leading edge of the first pulse received.

Encoding or decoding of track circuit pulses in the Electro Code 4 system uses microprocessor logic to determine the value of code pulses transmitted or received by the 2R converter module and 7K receiver module.

Structure of Track Code Pulses.

Electro Code 4 incorporates eight codes. Seven of the codes are used for controls and Code 6 is used as part of the tumble-down sequence during traffic reversal.

A brief description and its timing characteristics follows:

Each control code pulse is 115 milliseconds long, Code 1 the first pulse or the synchronizing pulse of the Electro Code, code structure, is used for three functions.

1. The leading edge of Code 1 is used to synchronize the turn on time of the return code pulses from the opposite end of the track circuit.

2. Timing of control code values is measured from the leading edge of code the first pulse (Code 1) to the leading edge of the second pulse (Codes 8,2,3,4 or 7).

3. The first pulse is called Code 1 and normally provides track circuit status.

Operation: 2R converter applies battery to rail for 115 milliseconds, then removes battery till the second 115 millisecond pulse is transmitted, then removes battery from the rail to complete the 1.4 second transmission time.

Figure 1 indicates Electro Code timing chart without Code 5.

Figure 2 indicates Electro Code timing chart with Code 5.

Code 1 - The first pulse of a 1.4 second transmission, provides track circuit relay information. System logic requires two consecutive Code 1 pulses be received to provide the track relay output. Loss of two consecutive Code 1 pulses causes loss of Code 1 relay.

The second code pulse of the 1.4 second transmission may be Code 8,2,3,4 or 7, dependent upon the system operation. A maximum of two code pulses may be transmitted in a transmission time frame of 1.4 seconds.

Code 8 - Most restrictive code of the vital code hierarchy. Timing 950 milliseconds leading edge Code 1 pulse to the leading edge of the Code 8 pulse. Application, control for first approach signal in a double approach signal application. Special application, Code 8 may be used for indication or special control function.

Code 2 - Second most restrictive code of the vital code hierarchy. Timing 695 milliseconds from leading edge Code 1 pulse to the leading edge of the Code 2 pulse. Normal application, approach aspect.

Code 3 - Third most restrictive code of vital code hierarchy. Timing 488 milliseconds from leading edge Code 1 pulse to the leading edge of the Code 3 pulse. Application various, some times used for advance approach or approach medium aspects.

Code 4 - Fourth most restrictive code of the vital code hierarchy. Timing 326 milliseconds from leading edge Code 1 pulse to the leading edge of Code 4 pulse. Application various, sometimes used for approach medium, approach limited, or clear aspects.

Code 7 - Least restrictive code of the vital code hierarchy. Timing 225 milliseconds from leading edge of Code 1 to the leading edge of the Code 7 pulse. Application various, sometimes used for approach medium, approach limited or clear aspects.

Code 5 - Provides a non-vital block occupancy indication code. Code 1, when transmitted without vital code is used for the Code 5 transmission by lengthening the Code 1 pulse to 225 milliseconds. When double pulse transmissions are made the vital code pulse is lengthened to 225 milliseconds. Refer to the 215 module for control of the Code 5 application. SECTION X

Code 6 - The application of a Code 6 control at an End-of-Siding location will cause the Code 1 pulse to lengthen to 550 milliseconds and remove the vital code from the code transmission to provide and accelerate tumble-down of opposing signals to stop. Code 6 is initiated either at an End-of-Siding location or it is done automatically by a train entering the track circuit. The Code 6 is cascaded through the block by the control logic in each intermediate Electro Code 4 assembly to the next track circuit.

Electro Code 4 equipment is packaged in several different configurations to perform various signal controls. These are:

ELECTRO CODE 4.....intermediate signal control assembly.

ELECTRO CODE 4H.....end of siding signal control assembly.

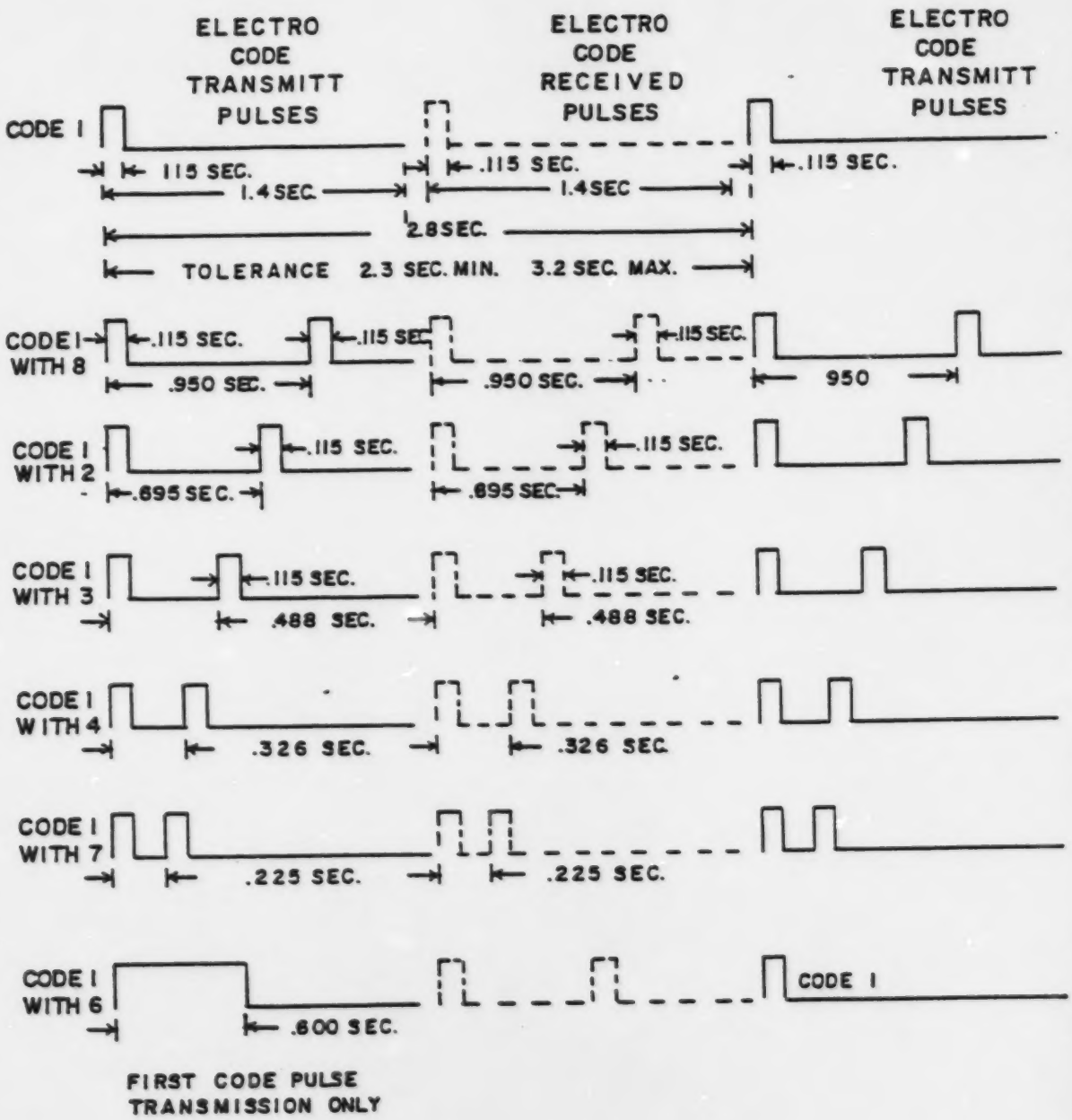
ELECTRO CODE 4R.....regenerative repeater.

ELECTRO LOCK 4.....electro lock operation.

ELECTRO CAB 4.....a cab signal generator.

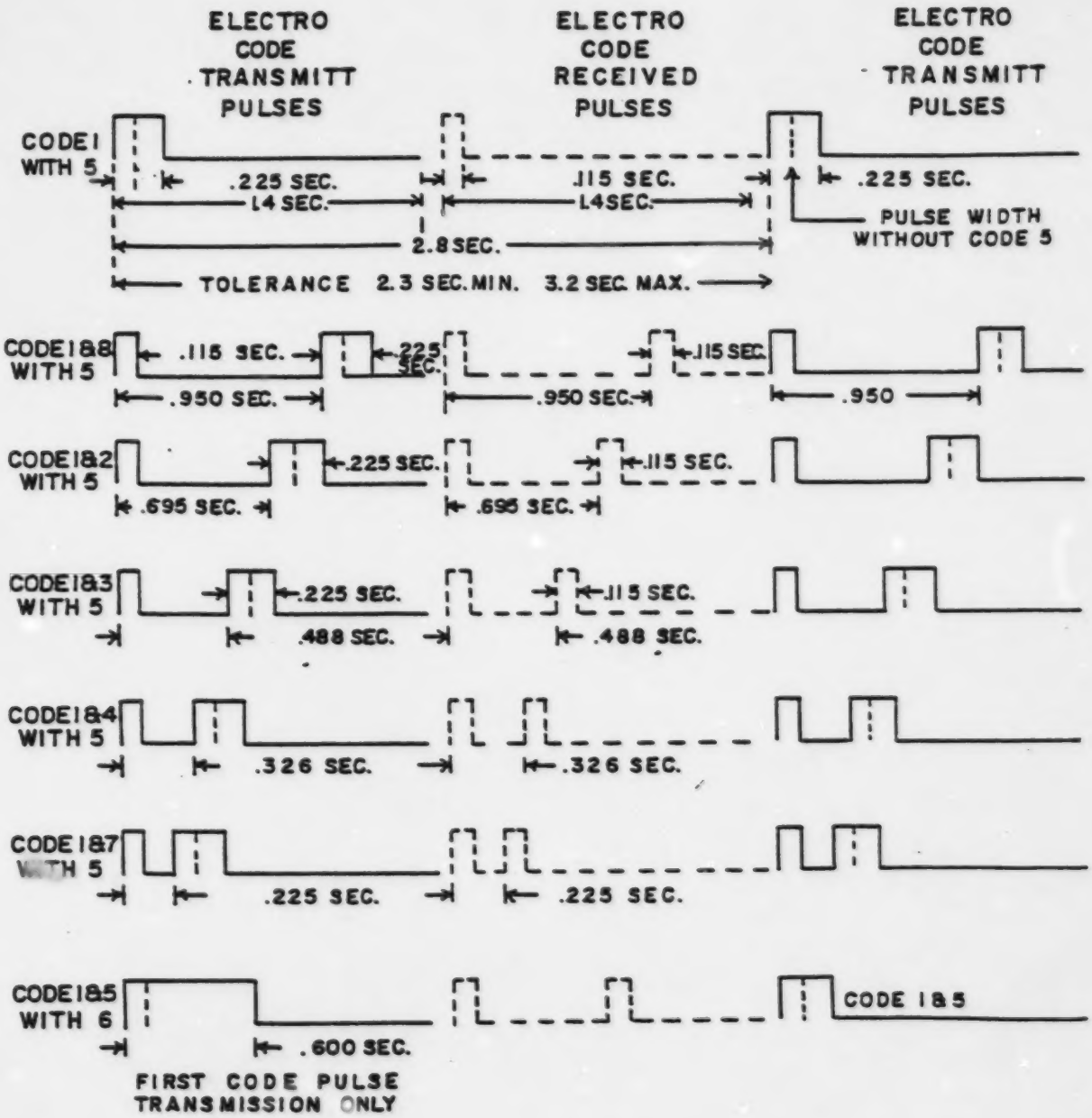
A detailed description of Electro Code equipment is given in Section VI of this manual. Section VII lists the circuit modules that are used with the Electro Code assemblies, with an explanation of their function.

Electro Code applications are illustrated in Section IX. These drawings show typical uses of Electro Code in different control circuits.



ELECTRO CODE TIMING CHART I

REFER TO SELECTION IV PAGE 2 FOR CODE PULSE TOLERANCES.



ELECTRO CODE TIMING CHART 2

WITH CODE 5 ADDED TO CODE PULSES.
REFER TO SECTION IV, PAGE 2 FOR CODE PULSE TOLERANCES.

TRACK CIRCUIT BI-DIRECTION CODING
TIME SHARE EXAMPLE

ELECTRO CODE 4

CIRCUIT COMPARSION

CT= 2R MODULE

CF= 7X MODULE

FILTER, DECODER, ENCODER CONTROL LOGIC EQUALS

214, 215, 210A AND

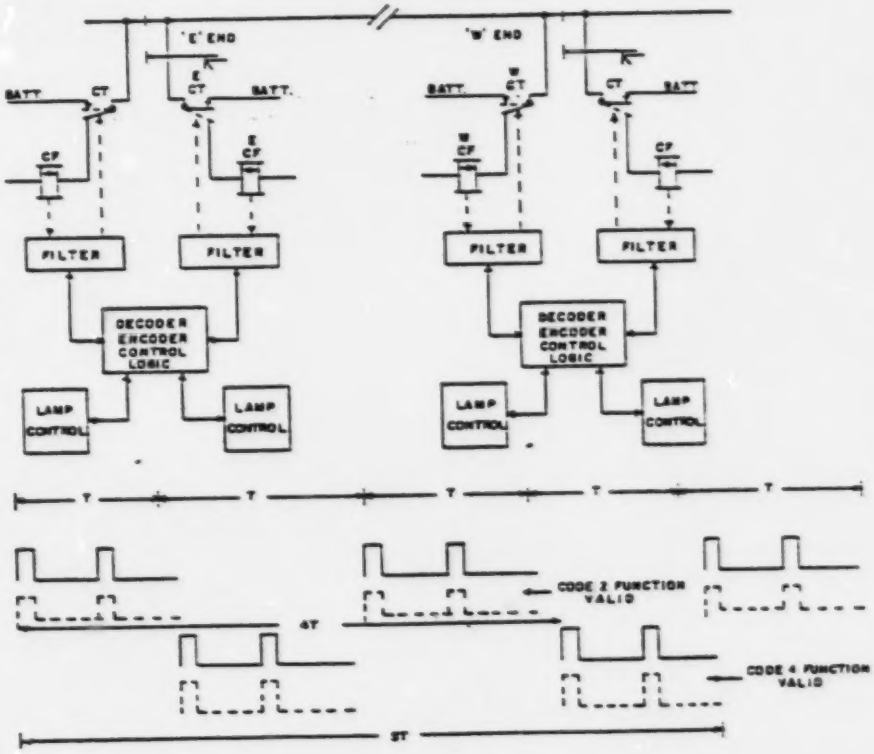
210B MODULES.

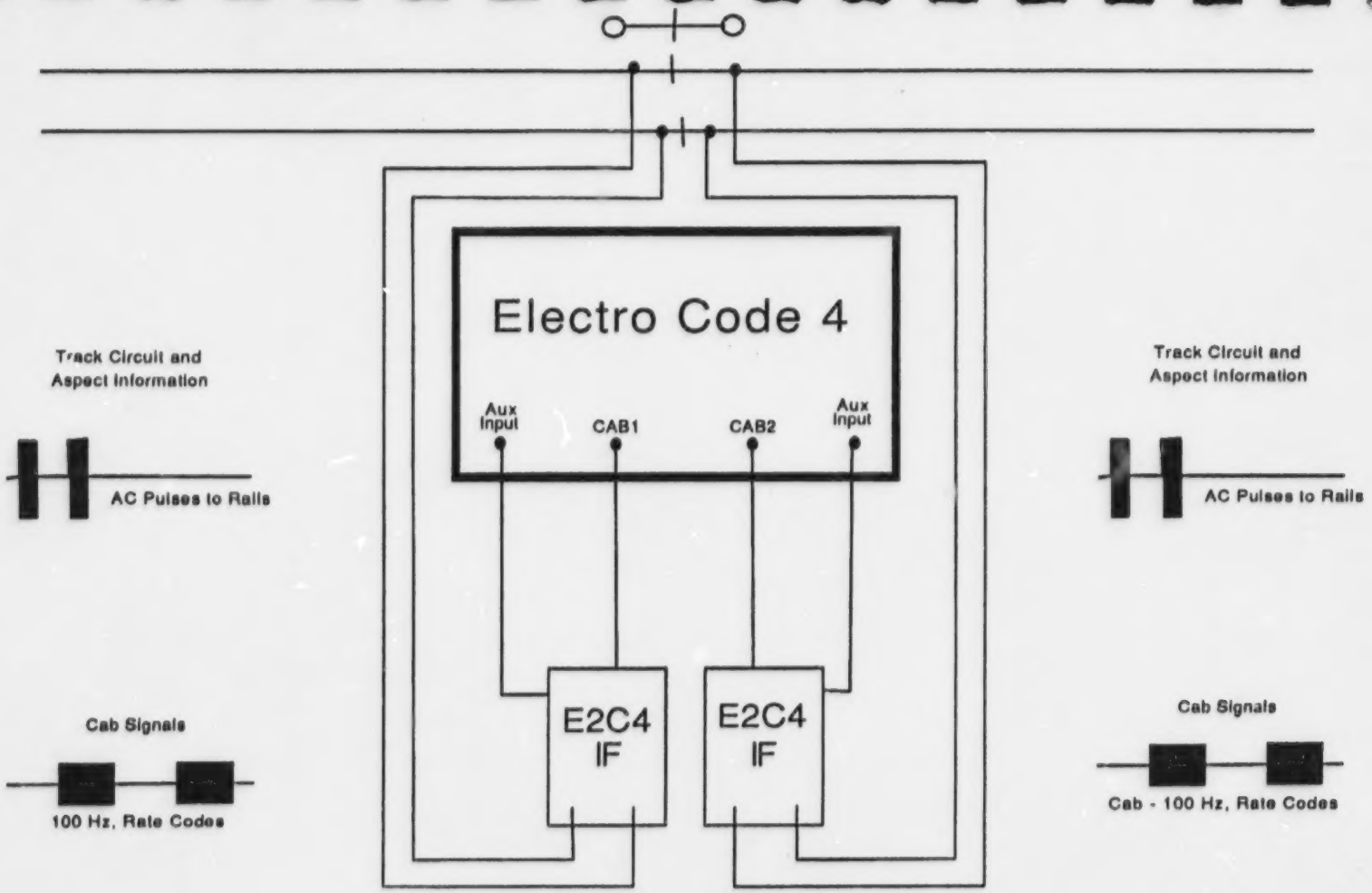
LAMP CONTROL EQUALS

211, 212 AND 213 MODULES

T=1.4 SECONDS

TWO CODE PULSE PAIRS RECIEVED REQUIRES 4T TIME AND EQUALS VALID CODE RECIEVED.

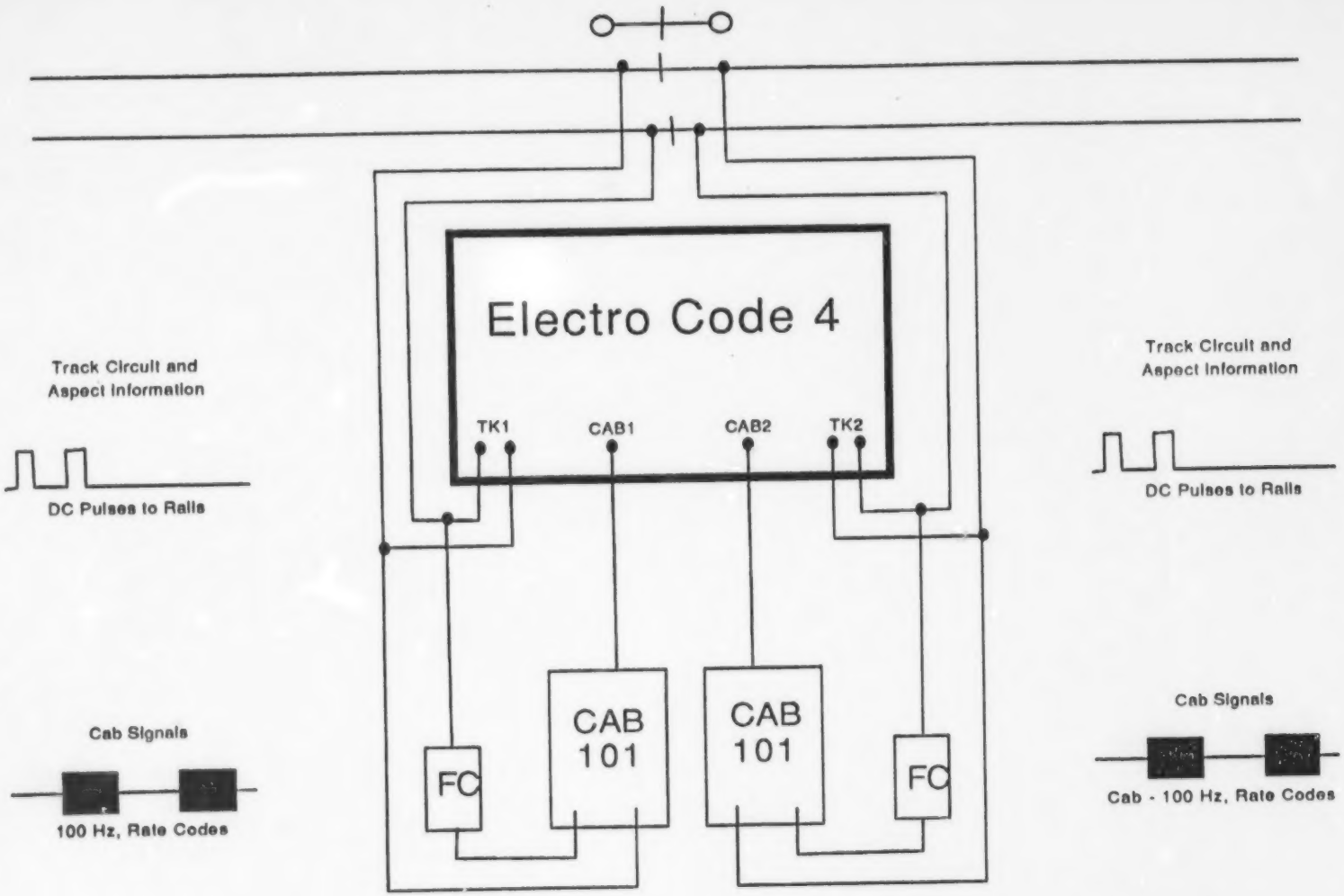




Electrified Electro Code 4 Application

Prototype Application at Shell Interlocking

11/26/91 jjc



Electro Code 4 Application

e.g. Atlantic City to Philadelphia

11/26/91 jjc

ULTRA – CAB

A NEW DIMENSION

IN

CAB SIGNALLING

AND

AUTOMATIC TRAIN CONTROL

PRESENTED BY: D. L. TURNER
PRODUCT MANAGER-TRAIN SYSTEMS
HARMON ELECTRONICS, INC.

HARMON ELECTRONICS, INC.
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9/90

SUMMARY

The Federal Railroad Administration requires that all trains operating on the Northeast Corridor be equipped with Automatic Train Control (ATC). Conventional ATC requires an air brake application within a few seconds after a more restrictive cab signal change occurs in the locomotive cab. The freight hauling railroads were concerned about immediate air brake application in freight trains because unduly high forces could occur in freight trains. They needed an ATC system that provided time for the engineer to adjust train slack before a brake application. Conrail engineers developed a specification for "Braking Profile Guidance". This method of train control gives the locomotive engineer flexibility to use air brakes, reduce throttle, use dynamic braking, or any combination of these. Braking Profile Guidance has been approved by the Federal Railroad Administration.

The **Locomotive Speed Limiter** (LSL), monitors the cab signal indication in the locomotive. Whenever a cab signal aspect changes to a more restrictive indication, the LSL invokes a Braking Profile curve to slow train speed to indicated cab signal status. If the engineer controls his train as usual and slows within the braking profile, the system does nothing. If the engineer fails to slow the train, the LSL will apply full service braking that cannot be revoked until the train stops. The profile curves ensure that the train can stop before the next signal with a generous safety margin. The information presented to the engineer includes train speed and time to penalty when a braking profile curve is activated. Deceleration and acceleration information are also provided. The advantages of this system include better running time, improved safety, reduction in maintenance costs and fuel costs. The system automatically switches to cab-signal mode in cab signal territory. The LSL works with existing cab signal equipment already present on the locomotive.

Requirements for a smaller, more capable Cab Signal Receiver dictated the design and development of a new Cab Signal Receiver. This new unit used a microprocessor-based design to achieve less than one-tenth the size of previously available equipment. It receives 40 HZ, 60 HZ, and 100 HZ coded cab signals in the track with an operating current range of anywhere from 0.5 amperes to over 35 amperes. It can also decode many more code rates, and all the aspects appearing on the wayside signals. The Ultra-Cab is an LSL combined with the new Cab Signal Receiver. When railroad operating requirements change, the Ultra-Cab equipment can accept revised software to implement changes.

Passenger train versions of Automatic Train Control use a Deceleration Assurance feature instead of Braking Profile Guidance.

Harmon Electronics

FEDERAL RAILROAD ADMINISTRATION

The Federal Railroad Administration requirements for Automatic Train Control on freight locomotives operating on the Northeast Corridor include:

A second display unit to provide operating status on the crew side of the locomotive cab

The version number of software program displayed during self test

All components soldered in place

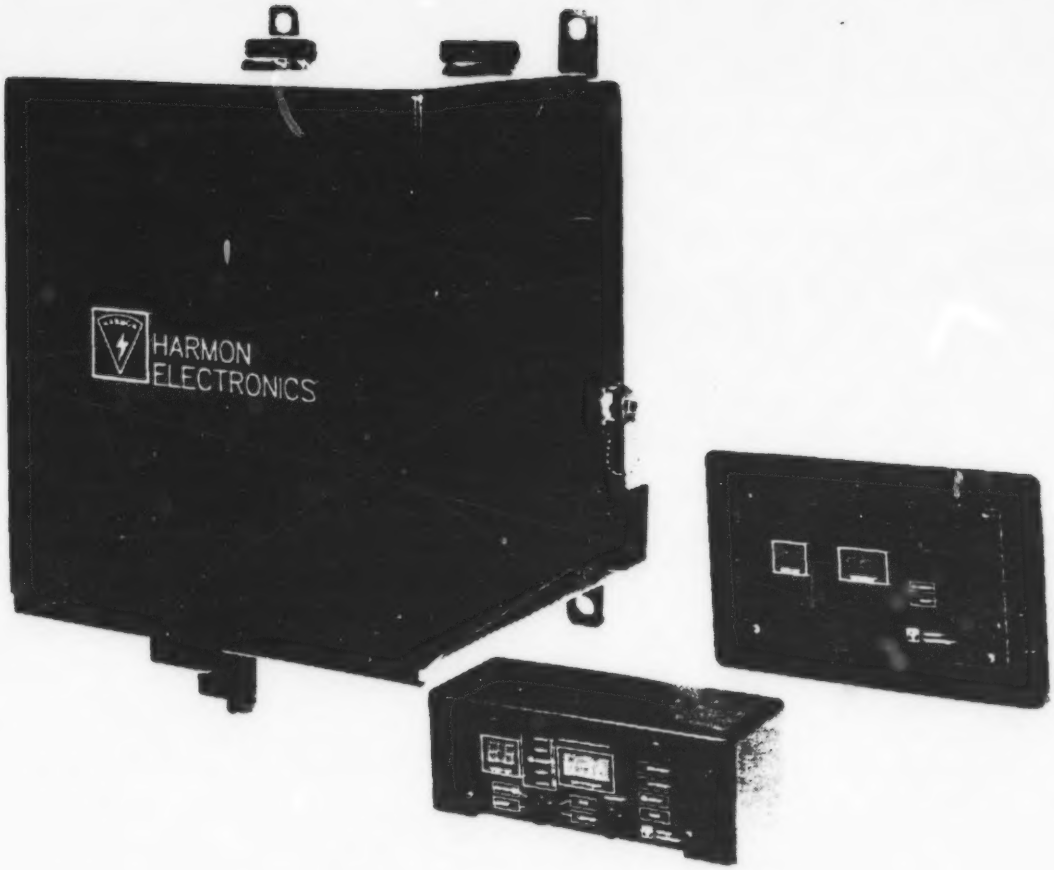
Running lights on each side of the locomotive to be lit when the Automatic Train Control equipment is active, thus providing for easy trackside observation that equipment is operating properly

FREIGHT RAILROAD DEVELOPMENT

The Northeast Corridor freight railroads studied conventional Train Control operational characteristics. This requires air brake application within a few seconds after the on-board cab signal equipment receives a more restrictive signal indication. Road tests and simulations showed that the sudden air brake applications required by the conventional train control equipment caused excessive forces in the train. The railroad concluded that a different method of train control was necessary to give the engineer time to adjust the slack in his train while slowing down to a more restrictive speed. Railroad engineers developed a concept called **Braking Profile Guidance**. Prototype systems employing this concept were tested at numerous locations on the Corridor and the tests proved that **Braking Profile Guidance** was indeed a superior method of train control. This method has since been approved by the Federal Railroad Administration and several hundred locomotives now are equipped with **Braking Profile Guidance.**

HARDWARE DESCRIPTION

The Automatic Train Control hardware is called **Locomotive Speed Limiter** (LSL). The LSL uses information from existing on-board cab signal equipment. The current cab signal indications provide input to the LSL. The LSL uses the different combinations of aspect changes to implement the correct profile guidance curve. The pictures on the facing page show a typical LSL system. The upper left hand picture shows the Logic Control Enclosure. The Logic Control Enclosure holds two removable modules. The next picture clock-wise shows the Crew Display which provides status information on the crew side of the cab. The Engineer's Display is mounted on the control stand where it is convenient for the engineer to operate the single control push button. The Magnet Valve applies the air brakes when engineer fails to comply with the profile guidance curve. One pressure switch is used during LSL self test and the other is used for a safety interlock during on-board cab signal tests. (On board tests meet Federal requirements) The two axle alternators used with the LSL system are not pictured; these are normally purchased directly by the railroad.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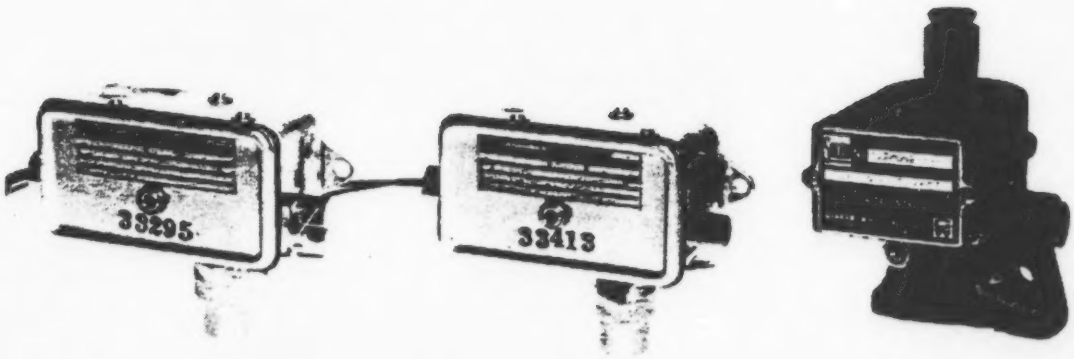
ELECTRONICS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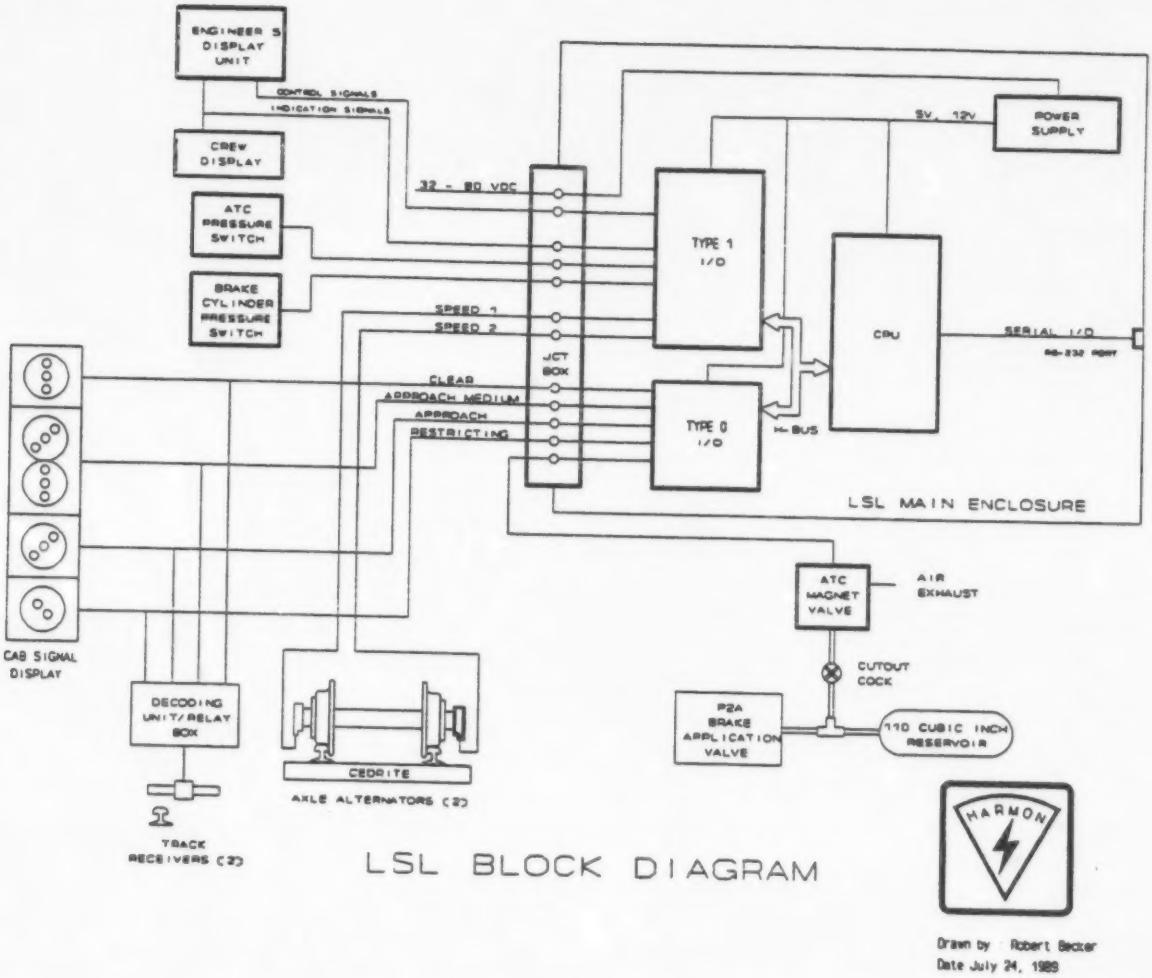
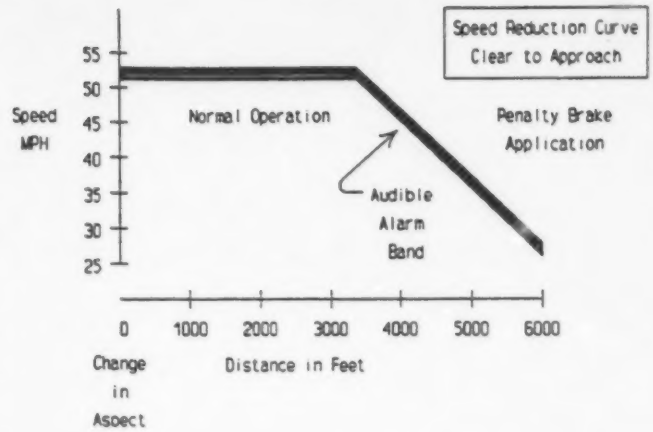


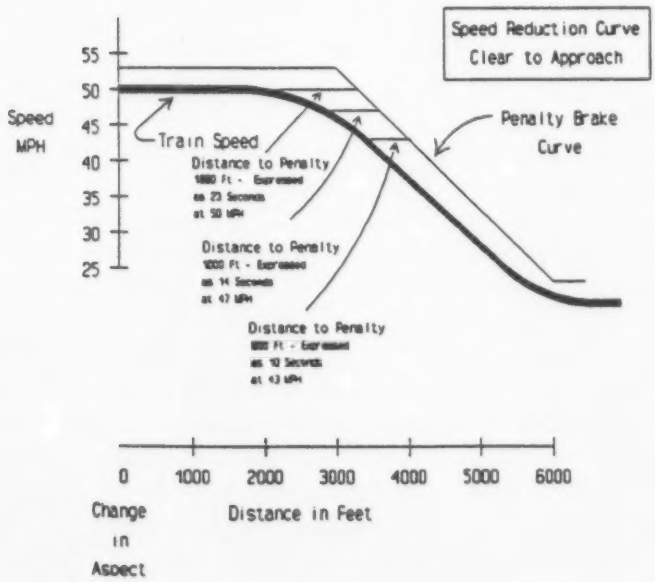
LSL BLOCK DIAGRAM

The block diagram above illustrates a typical LSL system installation. Existing cab signal equipment supplies input to the LSL. This particular application has four different cab signal aspects, although the LSL can accept up to nine. The magnet valve is connected with the P2A Application Valve. When the magnet valve is de-energized the P2A Application Valve causes a full service air brake application. The brakes cannot be released until the train stops. The system uses two axle alternators for redundant reliability.

BRAKING PROFILE GUIDANCE



Braking Profile Guidance curves are based on the stopping distance of the heaviest train and the shortest signal block. The curves also provide a generous safety margin. The braking profile on the right shows the transition from a clear to an approach signal aspect. The maximum clear speed on the Corridor is 50 MPH. The curve allows a one mile per hour pad and a two mile per hour warning band. A warning horn sounds when the speed enters the warning band. An air brake penalty is declared when the speed exceeds the top of the warning band; a speed which is three miles per hour above the nominal profile curve. Once penalty braking starts, it cannot be rescinded until the train stops. An additional Federal requirement was to prevent acceleration of the train when train enters a more restrictive block at a lower speed. An example of this is a train traveling at 35 miles per hour in a clear signal block. When such a train enters an approach block the system automatically implements a new speed limit of 38 miles per hour. This occurs for each variation of speed below the nominal maximum. The illustration to the left shows how the system provides ongoing information to the locomotive engineer as he slows his train. The illustration shows train speed and also the penalty brake curve. The distance to penalty is continuously monitored. As an example the distance to penalty is 1680 feet at 50 miles per hour. The display shows this as 23 seconds to penalty. The time is derived by dividing the current distance to penalty by the current velocity. The result is current time to penalty. In the illustration it is clear that the engineer has slowed his train and will successfully negotiate the profile guidance and reach the approach aspect target speed. The system also displays deceleration information in relation to the profile guidance curve. The displayed information helps the engineer to be certain that his rate of deceleration is sufficient to remain within the guidance profile.



DEPARTURE TESTS

The Locomotive Speed Limiter has two built-in test capabilities. The first is an internal self test which includes Random Access Memory test and Read Only Memory test. A number of other internal tests are also performed. The last sequence of tests assures that the air brakes can indeed be applied when a penalty braking action is initiated. The software version is displayed during the test in accordance with Federal requirements. The self test is completed in approximately 60 seconds. The test can only be done while the train is stopped. The second test is an on-board cab signal test. The test incudes a complete closed loop test of cab signal receiver response to every aspect code. The Automatic Train Stop function is also checked during this process. The test concludes with a measurement of the receiver coil impedance. Successful completion of the tests qualifies the locomotive for departure.

AUTOMATIC OPERATION

The Locomotive Speed Limiter can only operate in two modes when the train is in motion. These are non-cab and cab signal modes. The LSL automatically transfers into cab signal mode whenever a valid cab signal code is on the track. This feature makes operation automatic and simple. It can also be set up to automatically switch out of non cab signal mode or select new Braking Profile Curves when the train enters new territory with different operating speeds. On the Northeast Corridor maximum freight train speed is 50 miles per hour. When a train exits the Corridor a new higher speed limit is often allowed. The automatic transfer capability could be used to implement the new speed limits.

PASSENGER TRAIN OPERATION

The Automatic Train Control technique is modified for passenger train operation. Higher operating speeds and short trains dictate an emphasis on stopping distance assurance. Short trains with little slack action allow the immediate use of air brakes or brake blending to slow the train safely. A technique called Deceleration Assurance is used to ensure the train will comply with safe stopping distance. A more restrictive change in cab signal aspect requires a certain level of air brake application within a certain time period. When the application has occurred the rate of deceleration is monitored to assure that the current deceleration rate is meeting or exceeding a preset minimum. If the correct air brake application or deceleration rate requirements are not met a full service penalty is declared to reduce train speed to target speed indicated by current cab signal aspect. To facilitate timely schedules a means is provided for the engineer to exit the penalty condition when target speed is reached. The engineer is required to follow a predetermined procedure to exit the penalty. In the event the engineer was unable to respond the train would come to a full stop.

Old Technology

New Technology

CAB SIGNAL RECEIVER

The original Automatic Train Control equipment was intended to work with cab signal equipment already present on the locomotives. New locomotives and locomotives not already equipped with cab signal receivers were able to use new cab signal receivers which use new technology to provide an increased level of capability in a package size ten times smaller than existing equipment. This new equipment provided for an increased number of aspects, thus permitting cab signals in the locomotive to match wayside signals. A wide range of track currents and carrier frequencies could also be accepted by the receiver.

ULTRA-CAB SYSTEM

The combination of the Locomotive Speed Limiter and the new Cab Signal Receiver is called Ultra-Cab. The combined system provides the range of capabilities needed for freight or passenger operations. It is also adapted to multiple territory applications such as runthrough trains or passenger service around the country. Either Braking Profile Guidance or Deceleration Assurance can be used. The system includes built-in recorder capability which currently records speed and all internally available information relating to cab signal aspect and automatic train control functions. Recorder memory is solid state and memory is not lost when system power is removed. Typical memory time exceeds 48 hours. Alerter capability can also be incorporated in this system.

APPENDIX H

SENSITIVITY ANALYSES

Number	Scenario	Description
H.1	1	High Price of Diesel Fuel
H.2	1	Traffic Increase +20%
H.3	1	Traffic Decrease -20%
H.4	2	High Price of Diesel Fuel
H.5	2	Traffic Increase +20%
H.6	2	Traffic Decrease -20%
H.7	2	Signalling Costs - 0
H.8	2	Signalling Costs - Double
H.9	2	OCS Costs - +20%
H.10	2	OCS Costs - -20%
H.11	2	Electric Loco Price Decrease
H.12	3	High Price of Diesel Fuel
H.13	3	Traffic Increase +20%
H.14	3	Traffic Decrease -20%
H.15	3	Signalling Costs - 0
H.16	3	Signalling Costs - Double
H.17	3	OCS Costs - +20%
H.18	3	OCS Costs - -20%
H.19	3	Electric Loco Price Decrease
H.20	4	High Price of Diesel Fuel
H.21	4	Traffic Increase +20%
H.22	4	Traffic Decrease -20%
H.23	4	Signalling Costs - 0
H.24	4	Signalling Costs - Double
H.25	4	OCS Costs - +20%
H.26	4	OCS Costs - -20%
H.27	4	Electric Loco Price Decrease

TABLE H.1 File:fuelse1A

SCENARIO 1 Version: April 2/92

Sensitivity to Increase in Price of Diesel Fuel: Peak Price Oct./90

(All figures in millions unless otherwise stated)

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS												
		Energy:		Power				Rolling Stock												
	Seat Kms.	Diesel	Electric	Bureau	Htco.	Total Ope & Htco.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Htco Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL	
1	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
2	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
3	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
4	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
5	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
6	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
7	3736	6.7			19.5	26.2	0.0070											0.0	26.2	
8	3736	6.7			19.5	26.2	0.0070										12.7	12.7	38.9	
9	3736	6.7			19.5	26.2	0.0070										12.7	12.7	38.9	
10	3736	6.7			19.5	26.2	0.0070	60.0			445.5						12.7	518.2	544.4	
11	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
12	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
13	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
14	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
15	14324	24.5			34.6	59.1	0.0041	94.5										94.5	153.6	
16	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
17	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
18	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
19	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
20	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
21	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
22	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
23	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
24	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
25	14324	24.5			34.6	59.1	0.0041	54.0										54.0	113.1	
26	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
27	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
28	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
29	14324	24.5			34.6	59.1	0.0041											0.0	59.1	
30	14324	24.5			34.6	59.1	0.0041	(55.1)			(232.5)						(3.8)	(291.3)	(232.2)	
TOTAL	323840	557.5			887.7	1445.3	0.1528	153.4			213.0						34.2	400.7	1845.9	

PV Total Costs @ 3.75%	$1,140.7 (millions)
Life Cycle Average Cost	0.0068 ($/seat km)

TABLE H.2
SCENARIO 1
Sensitivity to Increases in Traffic: +20%
(All figures in millions unless otherwise stated)

File:trafsel1A

Version: April 2/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS														
		Energy:		Power					Rolling Stock													
	Seat Kms.	Diesel	Electric	Bureau	Htce.	Total Ops & Htce.	$ per Seat Km.	Diesels	Electric	RMU	Bi-levels	Civil	OCS	OCS Htce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL	PV Total Costs @ 3.75%	$1,286.5 (millions)
1	3736	4.5			19.5	24.0	0.0064											0.0	24.0	Life Cycle	0.0066
2	3736	4.5			19.5	24.0	0.0064											0.0	24.0	Average Cost	($/seat km)
3	3736	4.5			19.5	24.0	0.0064											0.0	24.0		
4	3736	4.5			19.5	24.0	0.0064											0.0	24.0		
5	3736	4.5			19.5	24.0	0.0064											0.0	24.0		
6	3736	4.5			19.5	24.0	0.0064											0.0	24.0		
7	3736	4.5			19.5	24.0	0.0064											0.0	24.0		
8	3736	4.5			19.5	24.0	0.0064										17.7	17.7	41.7		
9	3736	4.5			19.5	24.0	0.0064										17.7	17.7	41.7		
10	3736	4.5			19.5	24.0	0.0064	92.5			634.5						17.7	744.7	768.7		
11	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
12	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
13	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
14	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
15	17189	19.9			41.6	61.5	0.0036	94.5										94.5	156.0		
16	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
17	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
18	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
19	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
20	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
21	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
22	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
23	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
24	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
25	17189	19.9			41.6	61.5	0.0036	83.3										83.3	144.7		
26	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
27	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
28	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
29	17189	19.9			41.6	61.5	0.0036											0.0	61.5		
30	17189	19.9			41.6	61.5	0.0036	(79.2)			(310.0)						(5.3)	(394.5)	(333.1)		
TOTAL	381136	442.8			1027.0	1469.8	0.1359	191.0			324.5						47.7	563.2	2033.0		

TABLE H.3
SCENARIO 1
Sensitivity to Decreases in Traffic: -20%
(All figures in millions unless otherwise stated)

File:trafse18

Version: April 3/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064											0.0	24.0
2	3736	4.5			19.5	24.0	0.0064											0.0	24.0
3	3736	4.5			19.5	24.0	0.0064											0.0	24.0
4	3736	4.5			19.5	24.0	0.0064											0.0	24.0
5	3736	4.5			19.5	24.0	0.0064											0.0	24.0
6	3736	4.5			19.5	24.0	0.0064											0.0	24.0
7	3736	4.5			19.5	24.0	0.0064											0.0	24.0
8	3736	4.5			19.5	24.0	0.0064										7.7	7.7	31.7
9	3736	4.5			19.5	24.0	0.0064										7.7	7.7	31.7
10	3736	4.5			19.5	24.0	0.0064	27.5			256.5						7.7	291.7	315.7
11	11459	13.3			27.6	40.9	0.0036											0.0	40.9
12	11459	13.3			27.6	40.9	0.0036											0.0	40.9
13	11459	13.3			27.6	40.9	0.0036											0.0	40.9
14	11459	13.3			27.6	40.9	0.0036											0.0	40.9
15	11459	13.3			27.6	40.9	0.0036	94.5										94.5	135.4
16	11459	13.3			27.6	40.9	0.0036											0.0	40.9
17	11459	13.3			27.6	40.9	0.0036											0.0	40.9
18	11459	13.3			27.6	40.9	0.0036											0.0	40.9
19	11459	13.3			27.6	40.9	0.0036											0.0	40.9
20	11459	13.3			27.6	40.9	0.0036											0.0	40.9
21	11459	13.3			27.6	40.9	0.0036											0.0	40.9
22	11459	13.3			27.6	40.9	0.0036											0.0	40.9
23	11459	13.3			27.6	40.9	0.0036											0.0	40.9
24	11459	13.3			27.6	40.9	0.0036											0.0	40.9
25	11459	13.3			27.6	40.9	0.0036	24.8										24.8	65.6
26	11459	13.3			27.6	40.9	0.0036											0.0	40.9
27	11459	13.3			27.6	40.9	0.0036											0.0	40.9
28	11459	13.3			27.6	40.9	0.0036											0.0	40.9
29	11459	13.3			27.6	40.9	0.0036											0.0	40.9
30	11459	13.3			27.6	40.9	0.0036	(30.9)			(154.9)						(2.3)	(188.1)	(147.3)
TOTAL	266544	310.6			747.0	1057.6	0.1357	115.8			101.6						20.7	238.1	1295.7

PV Total Costs @ 3.75%	$805.4 (millions)
Life Cycle Average Cost	0.0057 ($/seat km)

TABLE H.6

SCENARIO 2

Sensitivity to Increase in Price of Diesel Fuel: Peak Price Oct./90

(All figures in millions except as otherwise stated)

File:2fuelsen

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS													
		Energy:		Power	Htce.	Total Ops	$ per	Rolling Stock				Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND	PV Total Costs	$1,207.3
	Seat Kms.	Diesel	Electric	Bureau		& Htce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL	@ 3.75	
																				Life Cycle	0.0072
1	3736	6.7			19.5	26.2	0.0070												26.2	Average Cost	($/seat km)
2	3736	6.7			19.5	26.2	0.0070												26.2		
3	3736	6.7			19.5	26.2	0.0070												26.2		
4	3736	6.7			19.5	26.2	0.0070												26.2		
5	3736	6.7			19.5	26.2	0.0070												26.2		
6	3736	6.7			19.5	26.2	0.0070												26.2		
7	3736	6.7			19.5	26.2	0.0070												26.2		
8	3736	6.7			19.5	26.2	0.0070					28.5					13.3	41.8	68.1		
9	3736	6.7			19.5	26.2	0.0070						38.2		17.5	27.5	13.3	96.4	122.7		
10	3736	6.7			19.5	26.2	0.0070	(12.6)	192.0		306.0		38.2	1.5	17.5	27.5	13.3	583.3	609.5		
11	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
12	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
13	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
14	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
15	14324	13.3	11.6	0.5	30.8	56.2	0.0039	67.5										67.5	123.7		
16	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
17	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
18	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
19	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
20	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
21	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
22	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
23	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
24	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
25	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
26	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
27	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
28	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
29	14324	13.3	11.6	0.5	30.8	56.2	0.0039											0.0	56.2		
30	14324	13.3	11.6	0.5	30.8	56.2	0.0039	(7.5)	(78.8)		(175.2)		(7.6)		(3.5)		(4.0)	(276.6)	(220.4)		
TOTAL	323840	332.3	232.6	10.0	811.7	1386.7	0.0487	47.4	113.2		130.8	28.5	68.7	1.5	31.4	55.0	36.0	512.4	1899.1		

TABLE N.5
SCENARIO 2
Sensitivity to Increases in Traffic: +20%
(All figures in millions except as otherwise stated)

File:2trafsen

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS												
		Energy:		Power	Htce.	Total Ops	$ per	Rolling Stock				Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND	PV Total Costs	$1,374.0
	Seat Kms.	Diesel	Electric	Bureau		& Htce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL	@ 3.75	
																				Life Cycle	0.0070
1	3736	4.5			19.5	24.0	0.0064												24.0	Average Cost	($/seat km)
2	3736	4.5			19.5	24.0	0.0064												24.0		
3	3736	4.5			19.5	24.0	0.0064												24.0		
4	3736	4.5			19.5	24.0	0.0064												24.0		
5	3736	4.5			19.5	24.0	0.0064												24.0		
6	3736	4.5			19.5	24.0	0.0064												24.0		
7	3736	4.5			19.5	24.0	0.0064												24.0		
8	3736	4.5			19.5	24.0	0.0064					28.5					18.3	46.8	70.9		
9	3736	4.5			19.5	24.0	0.0064						38.2		17.5	27.5	18.3	101.4	125.5		
10	3736	4.5			19.5	24.0	0.0064	(6.3)	228.0		466.5		38.2	1.5	17.5	27.5	18.3	791.1	815.2		
11	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
12	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
13	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
14	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
15	17189	10.7	13.9	0.5	36.6	61.8	0.0036	81.0										81.0	142.8		
16	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
17	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
18	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
19	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
20	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
21	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
22	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
23	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
24	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
25	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
26	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
27	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
28	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
29	17189	10.7	13.9	0.5	36.6	61.8	0.0036											0.0	61.8		
30	17189	10.7	13.9	0.5	36.6	61.8	0.0036	(9.0)	(93.6)		(241.1)		(7.6)		(3.5)		(5.5)	(360.3)	(298.5)		
TOTAL	381136	260.4	278.6	10.0	927.0	1476.1	0.1363	65.7	134.4		225.4	28.5	68.7	1.5	31.4	55.0	49.5	660.1	2136.2		

TABLE N.6
SCENARIO 2
Sensitivity to Decreases in Traffic: -20%
(All figures in millions except as otherwise stated)

File:2trafse1

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					28.5					8.3	36.8	60.9
9	3736	4.5			19.5	24.0	0.0064						38.2		17.5	27.5	8.3	91.4	115.5
10	3736	4.5			19.5	24.0	0.0064	(19.0)	156.0		145.5		38.2	1.5	17.5	27.5	8.3	375.5	399.5
11	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
12	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
13	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
14	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
15	11459	7.2	9.3	0.5	25.0	42.0	0.0037	54.0										54.0	96.0
16	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
17	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
18	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
19	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
20	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
21	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
22	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
23	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
24	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
25	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
26	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
27	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
28	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
29	11459	7.2	9.3	0.5	25.0	42.0	0.0037											0.0	42.0
30	11459	7.2	9.3	0.5	25.0	42.0	0.0037	(6.0)	(64.0)		(109.4)		(7.6)		(3.5)		(2.5)	(193.0)	(151.0)
TOTAL	266544	188.5	186.6	10.0	695.0	1080.1	0.1376	29.0	92.0		36.1	28.5	68.7	1.5	31.4	55.0	22.5	364.7	1444.9

PV Total Costs @ 3.75	$921.3
Life Cycle Average Cost	0.0065 ($/seat km)

TABLE H.7
SCENARIO 2
Sensitivity to Changes in Signalling Costs - O Costs

File: 2sigsen0

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9
9	3736	4.5			19.5	24.0	0.0064						38.2		17.5	2.5	13.3	71.4	95.5
10	3736	4.5			19.5	24.0	0.0064	(12.6)	192.0		306.0		38.2	1.5	17.5	2.5	13.3	558.3	582.3
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										67.5	119.4
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(78.8)		(175.2)		(7.6)		(3.5)		(4.0)	(276.6)	(224.7)
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036												
TOTAL	323840	224.5	232.6	10.0	811.7	1278.8	0.1369	47.4	113.2		130.8	28.5	68.7	1.5	31.4	5.0	36.0	462.4	1741.3

PV Total Costs @ 3.75 $1,112.7

Life Cycle Average Cost 0.0066 ($/seat km)

TABLE H.8
SCENARIO 2
Sensitivity to Changes in Signalling Costs - Double Costs
(All figures in millions except where otherwise stated)

File: 2sigserD

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9
9	3736	4.5			19.5	24.0	0.0064						38.2		17.5	52.5	13.3	121.4	145.5
10	3736	4.5			19.5	24.0	0.0064	(12.6)	192.0		306.0		38.2	1.5	17.5	52.5	13.3	608.3	632.3
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										67.5	119.4
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036												
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(78.8)		(175.2)		(7.6)		(3.5)		(4.0)	(276.6)	(226.7)
TOTAL	323840	224.5	232.6	10.0	811.7	1278.8	0.13[illegible]	47.4	113.2		130.8	28.5	68.7	1.5	31.4	105.0	36.0	562.4	1841.3

PV Total Costs @ 3.75	$1,183.2
Life Cycle Average Cost	0.0070 ($/seat km)

TABLE N.9
SCENARIO 2
Sensitivity to Changes in OCS Costs: +20%
(All figures in millions unless otherwise stated)

File:2ocssen1
Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS														
		Energy:		Power				Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND	PV Total Costs	$1,158.3
	Seat Kms.	Diesel	Electric	Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL	@ 3.75	
																				Life Cycle	0.0069
1	3736	4.5			19.5	24.0	0.0064												24.0	Average Cost	($/seat km)
2	3736	4.5			19.5	24.0	0.0064												24.0		
3	3736	4.5			19.5	24.0	0.0064												24.0		
4	3736	4.5			19.5	24.0	0.0064												24.0		
5	3736	4.5			19.5	24.0	0.0064												24.0		
6	3736	4.5			19.5	24.0	0.0064												24.0		
7	3736	4.5			19.5	24.0	0.0064												24.0		
8	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9		
9	3736	4.5			19.5	24.0	0.0064						45.8		17.5	27.5	13.3	104.1	128.1		
10	3736	4.5			19.5	24.0	0.0064	(12.6)	102.0		306.0		45.8	1.5	17.5	27.5	13.3	590.9	615.0		
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										67.5	119.4		
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9		
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(78.8)		(175.2)		(9.2)		(3.5)		(4.0)	(278.1)	(226.2)		
TOTAL	323840	224.5	232.6	10.0	811.7	1278.8	0.1369	47.4	113.2		130.8	28.5	82.4	1.5	31.4	55.0	36.0	526.2	1805.0		

TABLE N.10
SCENARIO 2
Sensitivity to Changes in OCS Costs: -20%
(All figures in millions unless otherwise stated)

File: 2ocssen2
Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ope & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9
8	3736	4.5			19.5	24.0	0.0064						30.5		17.5	27.5	13.3	88.8	112.9
9	3736	4.5			19.5	24.0	0.0064						30.5	1.5	17.5	27.5	13.3	575.7	599.7
10	3736	4.5			19.5	24.0	0.0064	(12.6)	192.0		306.0							0.0	51.9
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											67.5	119.4
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										0.0	51.9
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(78.8)		(175.2)		(6.1)		(3.5)		(4.0)	(275.1)	(223.2)
TOTAL	323840	224.5	232.6	10.0	811.7	1278.8	0.1369	47.4	113.2		130.8	28.5	54.9	1.5	31.4	55.0	36.0	498.7	1777.5

PV Total Costs @ 3.75	$1,137.7
Life Cycle Average Cost	0.0068 ($/seat km)

File:2elocsen

Version: March 8/92

TABLE H.11
SCENARIO 2
Sensitivity to a Decrease in the Cost of Electric Locomotives
(All figures in millions except where otherwise stated)

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Htce.	Total Ops & Htce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Htce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064					28.5					13.3	41.8	65.9
8	3736	4.5			19.5	24.0	0.0064						38.2		17.5	27.5	13.3	96.4	120.5
9	3736	4.5			19.5	24.0	0.0064						38.2	1.5	17.5	27.5	13.3	525.7	549.7
10	3736	4.5			19.5	24.0	0.0064	(12.6)	134.4		306.0							0.0	51.9
11	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
12	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
13	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
14	14324	9.0	11.6	0.5	30.8	51.9	0.0036											67.5	119.4
15	14324	9.0	11.6	0.5	30.8	51.9	0.0036	67.5										0.0	51.9
16	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
17	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
18	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
19	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
20	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
21	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
22	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
23	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
24	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
25	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
26	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
27	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
28	14324	9.0	11.6	0.5	30.8	51.9	0.0036											0.0	51.9
29	14324	9.0	11.6	0.5	30.8	51.9	0.0036	(7.5)	(55.2)		(175.2)		(7.6)		(3.5)		(4.0)	(253.0)	(201.1)
30	14324	9.0	11.6	0.5	30.8	51.9	0.0036												
TOTAL	323840	224.5	232.6	10.0	811.7	1278.8	0.1369	47.4	79.2		130.8	28.5	68.7	1.5	31.4	55.0	36.0	478.5	1757.3

PV Total Costs @ 3.75	$1,116.0
Life Cycle Average Cost	0.0066 ($/seat km)

TABLE H.12

SCENARIO 3

Sensitivity to Increases in the Price of Diesel Fuel - Peak October 1990

(All figures in millions unless otherwise stated)

File:scen3

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
								Rolling Stock				Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Energy: Diesel	Energy: Electric	Power Bureau	Htce.	Total Ops & Htce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	6.7			19.5	26.2	0.0070												26.2
2	3736	6.7			19.5	26.2	0.0070												26.2
3	3736	6.7			19.5	26.2	0.0070												26.2
4	3736	6.7			19.5	26.2	0.0070												26.2
5	3736	6.7			19.5	26.2	0.0070												26.2
6	3736	6.7			19.5	26.2	0.0070												26.2
7	3736	6.7			19.5	26.2	0.0070												26.2
8	3736	6.7			19.5	26.2	0.0070					30.8					13.3	44.1	70.4
9	3736	6.7			19.5	26.2	0.0070						97.5		35.6	55.0	13.3	201.3	227.6
10	3736	6.7			19.5	26.2	0.0070	(44.3)	354.0		306.0		97.5	3.0	35.6	55.0	13.3	820.1	846.3
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(145.3)		(175.2)		(19.5)		(7.1)		(4.0)	(351.1)	(296.9)
TOTAL	323840	67.3	441.5	10.0	827.7	1346.5	0.1459	(44.3)	208.7		130.8	30.8	175.4	3.0	64.0	110.0	36.0	714.5	2061.0

PV Total Costs @ 3.75	$1,365.3
Life Cycle Average Cost	0.0081 ($/seat km)

TABLE N.13
SCENARIO 3
Sensitivity to Increases in Traffic: +20%
(All figures in millions unless otherwise stated)

File:3trafsen

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					18.3	49.1	73.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	18.3	206.3	230.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	426.0		466.5		97.5	3.0	35.6	55.0	18.3	1057.6	1081.6
11	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
12	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
13	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
14	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
15	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
16	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
17	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
18	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
19	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
20	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
21	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
22	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
23	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
24	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
25	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
26	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
27	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
28	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
29	17189	0.0	26.5	0.5	36.9	63.9	0.0037											0.0	63.9
30	17189	0.0	26.5	0.5	36.9	63.9	0.0037		(176.8)		(241.1)		(19.5)		(7.1)		(5.5)	(448.0)	(384.1)
TOTAL	381136	45.5	529.5	10.0	933.0	1518.0	0.1387	(44.3)	251.2		225.4	30.8	175.4	3.0	64.0	110.0	49.5	865.1	2383.1

PV Total Costs @ 3.75	$1,579.9
Life Cycle Average Cost	0.0081 ($/seat km)

TABLE H.14

SCENARIO 3

Sensitivity to Decreases in Traffic: -20%

(All figures in millions unless otherwise stated)

File:3trafse1

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
			Energy:	Power				Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric	Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					8.3	39.1	63.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	8.3	196.3	220.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	282.0		145.5		97.5	3.0	35.6	55.0	8.3	582.6	606.6
11	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
12	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
13	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
14	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
15	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
16	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
17	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
18	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
19	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
20	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
21	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
22	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
23	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
24	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
25	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
26	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
27	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
28	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
29	11459	0.0	17.7	0.5	26.3	44.5	0.0039											0.0	44.5
30	11459	0.0	17.7	0.5	26.3	44.5	0.0039		(115.7)		(109.4)		(19.5)		(7.1)		(2.5)	(254.2)	(209.7)
TOTAL	266544	45.5	353.4	10.0	721.0	1129.9	0.1420	(44.3)	166.3		36.1	30.8	175.6	3.0	64.0	110.0	22.5	563.9	1693.8

PV Total Costs @ 3.75	$1,114.2
Life Cycle Average Cost	0.0079 ($/seat km)

TABLE N.15
SCENARIO 3
Sensitivity to Changes in the Cost of Signalling - 0 Costs
(All figures in millions unless otherwise stated)

File:3sigsen0
Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
																			24.0
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
8	3736	4.5			19.5	24.0	0.0064						97.5		35.6	5.0	13.3	151.3	175.4
9	3736	4.5			19.5	24.0	0.0064						97.5	3.0	35.6	5.0	13.3	770.1	794.1
10	3736	4.5			19.5	24.0	0.0064	(44.3)	354.0		306.0							0.0	54.2
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(145.3)		(175.2)		(19.5)		(7.1)		(4.0)	(351.1)	(296.9)
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038												
TOTAL	323840	45.5	441.5	10.0	827.7	1324.7	0.1401	(44.3)	208.7		130.8	30.8	175.4	3.0	64.0	10.0	36.0	614.5	1939.2

PV Total Costs @ 3.75	$1,276.9
Life Cycle Average Cost	0.0076 ($/seat km)

TABLE H.16
SCENARIO 3
Sensitivity to Changes in the Cost of Signalling - Double Costs
(All figures in millions unless otherwise stated)

File:3sigcerD

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3756	4.5			19.5	24.0	0.0064												24.0
2	3756	4.5			19.5	24.0	0.0064												24.0
3	3756	4.5			19.5	24.0	0.0064												24.0
4	3756	4.5			19.5	24.0	0.0064												24.0
5	3756	4.5			19.5	24.0	0.0064												24.0
6	3756	4.5			19.5	24.0	0.0064												24.0
7	3756	4.5			19.5	24.0	0.0064												24.0
8	3756	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3756	4.5			19.5	24.0	0.0064						97.5		35.6	105.0	13.3	251.3	275.4
10	3756	4.5			19.5	24.0	0.0064	(44.3)	354.0		306.0		97.5	3.0	35.6	105.0	13.3	870.1	896.1
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(145.3)		(175.2)		(19.5)		(7.1)		(4.0)	(351.1)	(296.9)
TOTAL	323040	45.5	441.5	10.0	827.7	1324.7	0.1401	(44.3)	208.7		130.8	30.8	175.4	3.0	64.0	210.0	36.0	814.5	2139.2

PV Total Costs @ 5.75	$1,417.9
Life Cycle Average Cost	0.0086 ($/seat km)

TABLE H.17
SCENARIO 3
Sensitivity to Changes in Cost of OCS: +20%
(All figures in millions unless otherwise noted)

File:3ocsen1

Version: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$/ Seat Km.	CAPITAL COSTS Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						116.9		35.6	55.0	13.3	220.8	244.9
10	3736	4.5			19.5	24.0	0.0064	(44.3)	354.0		306.0		116.9	3.0	35.6	55.0	13.3	839.6	863.6
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(165.3)		(175.2)		(23.4)		(7.1)		(4.0)	(355.0)	(300.8)
TOTAL	323840	45.5	441.5	10.0	827.7	1324.7	0.1401	(44.3)	208.7		130.8	30.8	210.5	3.0	64.0	110.0	36.0	749.6	2074.2

PV Total Costs @ 3.75	$1,373.6
Life Cycle Average Cost	0.0082 $/seat km)

TABLE H.18
SCENARIO 3
Sensitivity to Changes in Cost of OCS: -20%
(All figures in millions unless otherwise noted)

File:3ocssen2

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
			Energy:	Power				Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric	Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						78.0		35.6	55.0	13.3	181.8	205.9
10	3736	4.5			19.5	24.0	0.0064	(44.3)	354.0		306.0		78.0	3.0	35.6	55.0	13.3	800.6	824.6
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(165.3)		(175.2)		(15.6)		(7.1)		(4.0)	(347.2)	(293.0)
TOTAL	323840	45.5	441.5	10.0	827.7	1324.7	0.1401	(44.3)	208.7		130.8	30.8	140.3	3.0	64.0	110.0	36.0	679.4	2006.1

PV Total Costs @ 3.75	$1,321.2
Life Cycle Average Cost	0.0078 ($/seat km)

TABLE H.19
SCENARIO 3
Sensitivity to Decrease in the Cost of Electric Locomotives
(All figures in millions except where otherwise noted)

File:3elocsen

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
									Rolling Stock			Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Energy: Diesel	Energy: Electric	Power Bureau	Htce.	Total Ops & Htce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	13.3	201.3	225.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	247.8		306.0		97.5	3.0	35.6	55.0	13.3	713.9	737.9
11	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
12	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
13	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
14	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
15	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
16	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
17	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
18	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
19	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
20	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
21	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
22	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
23	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
24	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
25	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
26	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
27	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
28	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
29	14324	0.0	22.1	0.5	31.6	54.2	0.0038											0.0	54.2
30	14324	0.0	22.1	0.5	31.6	54.2	0.0038		(101.7)		(175.2)		(19.5)		(7.1)		(4.0)	(307.5)	(253.3)
TOTAL	323840	45.5	441.5	10.0	827.7	1324.7	0.1401	(44.3)	146.1		130.8	30.8	175.4	3.0	64.0	110.0	36.0	651.9	1976.5

PV Total Costs @ 3.75	$1,288.4
Life Cycle Average Cost	0.0076 ($/seat km)

TABLE H.20

SCENARIO 4

Sensitivity to Increases in the Price of Diesel Fuel - Peak October 1990

(All figures in millions unless otherwise stated)

File:4fuelsen

Version: March 6/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS												
								Rolling Stock												
	Seat Kms.	Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Diesels	Electric	EMU	Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL	PV Total Costs @ 3.75	$1,401.8
																				Life Cycle Average Cost	0.0083 ($/seat km)
1	3736	6.7			19.5	26.2	0.0070												26.2		
2	3736	6.7			19.5	26.2	0.0070												26.2		
3	3736	6.7			19.5	26.2	0.0070												26.2		
4	3736	6.7			19.5	26.2	0.0070												26.2		
5	3736	6.7			19.5	26.2	0.0070												26.2		
6	3736	6.7			19.5	26.2	0.0070												26.2		
7	3736	6.7			19.5	26.2	0.0070												26.2		
8	3736	6.7			19.5	26.2	0.0070					30.8					13.3	44.1	70.4		
9	3736	6.7			19.5	26.2	0.0070						97.5		35.6	55.0	13.3	201.3	227.6		
10	3736	6.7			19.5	26.2	0.0070	(44.3)	192.0	345.0	184.5		97.5	3.0	35.6	55.0	13.3	881.6	907.8		
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(78.8)	(141.6)	(125.4)		(19.5)		(7.1)		(4.0)	(376.3)	(321.9)		
TOTAL	323840	67.3	358.2	10.0	915.7	1351.3	0.1462	(44.3)	113.2	203.4	59.1	30.8	175.4	3.0	64.0	110.0	36.0	750.7	2102.0		

TABLE H.21
SCENARIO 4
Sensitivity to Increases in Traffic: +20%
(All figures in millions unless otherwise stated)

File:4trafsen

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS												
			Energy:		Power	Htce.	Total Ops	$ per	Rolling Stock				Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric		Bureau		& Htce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5				19.5	24.0	0.0064												24.0
2	3736	4.5				19.5	24.0	0.0064												24.0
3	3736	4.5				19.5	24.0	0.0064												24.0
4	3736	4.5				19.5	24.0	0.0064												24.0
5	3736	4.5				19.5	24.0	0.0064												24.0
6	3736	4.5				19.5	24.0	0.0064												24.0
7	3736	4.5				19.5	24.0	0.0064												24.0
8	3736	4.5				19.5	24.0	0.0064					30.8					18.3	49.1	73.2
9	3736	4.5				19.5	24.0	0.0064						97.5		35.6	55.0	18.3	206.3	230.4
10	3736	4.5				19.5	24.0	0.0064	(44.3)	228.0	415.0	283.5		97.5	3.0	35.6	55.0	18.3	1091.6	1115.6
11	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
12	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
13	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
14	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
15	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
16	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
17	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
18	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
19	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
20	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
21	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
22	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
23	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
24	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
25	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
26	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
27	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
28	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
29	17189	0.0	21.5		0.5	42.2	64.2	0.0037											0.0	64.2
30	17189	0.0	21.5		0.5	42.2	64.2	0.0037		(93.6)	(170.3)	(166.0)		(19.5)		(7.1)		(5.5)	(461.9)	(397.7)
TOTAL	381136	45.5	430.2		10.0	1039.0	1524.7	0.1391	(44.3)	134.4	244.7	117.5	30.8	175.4	3.0	64.0	110.0	49.5	885.1	2409.8

PV Total Costs @ 3.75	$1,602.0
Life Cycle Average Cost	0.0082 $/seat km)

TABLE H.22
SCENARIO 4
Sensitivity to Decreases in Traffic: -20%
(All figures in millions unless otherwise stated)

File:4trafse1

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
	Seat Kms.	Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	Rolling Stock: Diesels	Rolling Stock: Electric	Rolling Stock: EMU	Rolling Stock: Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					8.3	39.1	63.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	8.3	196.3	220.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	156.0	275.0	85.5		97.5	3.0	35.6	55.0	8.3	671.6	695.6
11	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
12	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
13	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
14	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
15	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
16	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
17	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
18	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
19	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
20	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
21	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
22	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
23	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
24	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
25	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
26	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
27	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
28	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
29	11459	0.0	14.3	0.5	29.8	44.6	0.0039											0.0	44.6
30	11459	0.0	14.3	0.5	29.8	44.6	0.0039		(64.0)	(112.8)	(84.7)		(19.5)		(7.1)		(2.5)	(290.7)	(246.1)
TOTAL	266544	45.5	286.2	10.0	791.0	1132.6	0.1422	(44.3)	92.0	162.2	0.8	30.8	175.4	3.0	64.0	110.0	22.5	616.4	1749.0

PV Total Costs @ 3.75	$1,165.0
Life Cycle Average Cost	0.0083 ($/seat km)

TABLE H.23
SCENARIO 4
Sensitivity to Changes in the Cost of Signalling - 0 Costs
(All figures in millions unless otherwise stated)

File:4sigsen0

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:		Power	Mtce.	Total Ops	$ per	Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric	Bureau		& Mtce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	5.0	13.3	151.3	175.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	192.0	345.0	184.5		97.5	3.0	35.6	5.0	13.3	831.6	855.6
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(78.8)	(141.6)	(125.4)		(19.5)		(7.1)		(4.0)	(376.3)	(321.9)
TOTAL	323840	45.5	358.2	10.0	915.7	1329.4	0.1404	(44.3)	113.2	203.4	59.1	30.8	175.4	3.0	64.0	10.0	36.0	650.7	1980.1

PV Total Costs @ 3.75	$1,313.4
Life Cycle Average Cost	0.0078 ($/seat km)

TABLE H.24
SCENARIO 4
Sensitivity to Changes in the Cost of Signalling - Double Costs
(All figures in millions except where otherwise stated)

File:4sigserD

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS												
		Energy:		Power	Htce.	Total Ope	$ per	Rolling Stock				Civil	OCS	OCS Htce	Sub-	Signals/	Shops	Total	GRAND	PV Total Costs @ 3.75	$1,454.4
	Seat Kms.	Diesel	Electric	Bureau		& Htce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL		
																				Life Cycle Average Cost	0.0086 ($/seat km)
1	3736	4.5			19.5	24.0	0.0064												24.0		
2	3736	4.5			19.5	24.0	0.0064												24.0		
3	3736	4.5			19.5	24.0	0.0064												24.0		
4	3736	4.5			19.5	24.0	0.0064												24.0		
5	3736	4.5			19.5	24.0	0.0064												24.0		
6	3736	4.5			19.5	24.0	0.0064												24.0		
7	3736	4.5			19.5	24.0	0.0064												24.0		
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2		
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	105.0	13.3	251.3	275.4		
10	3736	4.5			19.5	24.0	0.0064	(44.3)	192.0	345.0	184.5		97.5	3.0	35.6	105.0	13.3	931.6	955.6		
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4		
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(78.8)	(141.6)	(125.4)		(19.5)		(7.1)		(4.0)	(376.3)	(321.9)		
TOTAL	323840	45.5	358.2	10.0	915.7	1329.4	0.1404	(44.3)	113.2	203.4	59.1	30.8	175.4	3.0	64.0	210.0	36.0	850.7	2180.1		

TABLE H.25
SCENARIO 4
Sensitivity to Changes in the Cost of OCS: +20%
(All figures in millions unless otherwise stated)

File:4ocssen1

Verion: March 8/92

YEAR	TRAFFIC Seat Kms.	OPERATING & MAINTENANCE COSTS Energy: Diesel	Energy: Electric	Power Bureau	Mtce.	Total Ops & Mtce.	$ per Seat Km.	CAPITAL COSTS Rolling Stock Diesels	Rolling Stock Electric	Rolling Stock EMU	Rolling Stock Bi-levels	Civil	OCS	OCS Mtce Eqpt.	Sub-Stations	Signals/ Comms.	Shops Elec/Mec	Total Cap.Costs	GRAND TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						116.9		35.6	55.0	13.3	220.8	244.9
10	3736	4.5			19.5	24.0	0.0064	(44.3)	192.0	345.0	184.5		116.9	3.0	35.6	55.0	13.3	901.1	925.1
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(78.8)	(141.6)	(125.4)		(23.4)		(7.1)		(4.0)	(380.2)	(325.8)
TOTAL	323840	45.5	358.2	10.0	915.7	1329.4	0.1404	(44.3)	113.2	203.4	59.1	30.8	210.5	3.0	64.0	110.0	36.0	785.8	2115.2

PV Total Costs @ 3.75	$1,410.1
Life Cycle Average Cost	0.0084 ($/seat km)

TABLE H.26
SCENARIO 4
Sensitivity to Changes in the Cost of OCS: -20%
(All figures in millions unless otherwise stated)

File:4ocssen2

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:		Power	Mtce.	Total Ops	$ per	Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric	Bureau		& Mtce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						78.0		35.6	55.0	13.3	181.8	205.9
10	3736	4.5			19.5	24.0	0.0064	(44.3)	192.0	345.0	184.5		78.0	3.0	35.6	55.0	13.3	862.1	886.1
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(78.8)	(141.6)	(125.4)		(15.6)		(7.1)		(4.0)	(372.4)	(318.0)
TOTAL	323840	45.5	358.2	10.0	915.7	1329.4	0.1404	(44.3)	113.2	203.4	59.1	30.8	140.3	3.0	64.0	110.0	36.0	715.7	2045.1

PV Total Costs @ 3.75	$1,357.7
Life Cycle Average Cost	0.0081 ($/seat km)

TABLE H.27
SCENARIO 4
Sensitivity to a Decrease in the Price of Electric Locos
(All figures in millions unless otherwise stated)

File: 4elocsen

Version: March 8/92

YEAR	TRAFFIC	OPERATING & MAINTENANCE COSTS						CAPITAL COSTS											
		Energy:		Power	Mtce.	Total Ope	$ per	Rolling Stock				Civil	OCS	OCS Mtce	Sub-	Signals/	Shops	Total	GRAND
	Seat Kms.	Diesel	Electric	Bureau		& Mtce.	Seat Km.	Diesels	Electric	EMU	Bi-levels			Eqpt.	Stations	Comms.	Elec/Mec	Cap.Costs	TOTAL
1	3736	4.5			19.5	24.0	0.0064												24.0
2	3736	4.5			19.5	24.0	0.0064												24.0
3	3736	4.5			19.5	24.0	0.0064												24.0
4	3736	4.5			19.5	24.0	0.0064												24.0
5	3736	4.5			19.5	24.0	0.0064												24.0
6	3736	4.5			19.5	24.0	0.0064												24.0
7	3736	4.5			19.5	24.0	0.0064												24.0
8	3736	4.5			19.5	24.0	0.0064					30.8					13.3	44.1	68.2
9	3736	4.5			19.5	24.0	0.0064						97.5		35.6	55.0	13.3	201.3	225.4
10	3736	4.5			19.5	24.0	0.0064	(44.3)	134.4	345.0	124.5		97.5	3.0	35.6	55.0	13.3	824.0	848.0
11	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
12	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
13	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
14	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
15	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
16	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
17	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
18	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
19	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
20	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
21	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
22	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
23	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
24	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
25	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
26	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
27	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
28	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
29	14324	0.0	17.9	0.5	36.0	54.4	0.0038											0.0	54.4
30	14324	0.0	17.9	0.5	36.0	54.4	0.0038		(55.2)	(141.6)	(125.4)		(19.5)		(7.1)		(4.0)	(352.7)	(298.2)
TOTAL	323840	45.5	358.2	10.0	915.7	1329.4	0.1404	(44.3)	79.2	203.4	59.1	30.8	175.4	3.0	64.0	110.0	36.0	716.8	2046.2

PV Total Costs @ 3.75	$1,351.8
Life Cycle Average Cost	0.0080 ($/seat km)